Designing information hotspots for the surgical suite: How architecture, artifacts, and people's behavior converge to support coordination.

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Abstract

Shared information displays are increasingly present in built environments. Terminal displays in airports show arrival and departure information, monitors in hotels and convention centers show room assignments, and whiteboards in hospitals show schedules and help staff know what others are doing. One of the most important types of displays is the schedule board for surgical suites. Surgical suites are a highly dynamic setting, where doctors, nurses, equipment, rooms, and patients must be perfectly coordinated. Schedule changes occur frequently and must be shared among staff. This research examines the design of hospital architecture (placement of walls, corridors, furnishings) and information artifacts for more effective information sharing and coordination of surgeries.

I conducted field studies in four hospital surgical suites and a survey of surgical suite directors nationwide. I describe factors of the architecture, and information available around surgical suite schedule displays that are associated with information sharing and coordination outcomes.

From the field studies, I developed the concept of an information hotspot – a place where people congregate to receive and provide information, public displays offer up-to-date information, and coordination workers answer questions, resolve conflicts, and keep information up-to-date. The information hotspot concept guided my design research. I developed design principles for the placement of schedule boards and control desks; design guidelines for the location of surgical suite displays and control desks; an evaluation list for surgical suites; and a three-tiered design intervention strategy ranging in implementation effort.

In a follow-up national survey of surgical suite directors, I studied linkages between surgical suite architecture, information artifacts and communication practices, workplace characteristics, information sharing, and coordination speed and stress. I found that visibility between the schedule board and control desk in the surgical suite, traffic-free areas around the schedule board, and complete, up-to-date schedule board information were related to information sharing and coordination outcomes.

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Dedicated to
Kelly,
Gian and Carol,
Andy, and Johnmarco.

Chapter 1: General Introduction

Large public information displays increasingly pervade the built environment. For example, airports have terminal displays showing arrival and departure information, hotels and convention centers often feature large monitors showing room assignments and daily schedules, and in hospitals, large displays show the status of pharmacy prescriptions, and the status of ongoing surgeries (see Figure 1-1). While considerable human-computer interaction (HCI) research has addressed features of such displays that make them successful or unsuccessful (e.g., Huang, Mynatt, Russell, & Sue, 2006; Widgor, Shen, Forlines, & Balakrishnan, 2006; Su & Bailey, 2005; Hawkey, Kellar, Reilly, Whalen, & Inkpen, 2006; Bardram Hansen, & Soegaard, 2006), researchers have rarely considered how the architecture of the built environment and artifacts surrounding large displays are associated with how people move, pause, interact with each other, and use information displays.

Figure 1-1. From left to right, airport terminal display, pharmacy prescription display, and hospital trauma unit patient display.

The premise of this thesis is that the placement of large information displays in the architecture of buildings is a critical factor in deployment success. In particular, I focus on how aspects of the architecture in conjunction with the information displayed influence communication and collaboration within and between work groups. My specific application domain is hospital surgical suites, a setting where the rapid exchange of information is especially important and highly driven by a large public information display, the surgical suite schedule whiteboard. [1]

In the remainder of this introduction, I first review literature on how the architecture of buildings shapes interaction; then, I discuss how the positioning of information technology (IT) in buildings influences what information people choose to display and how that information is used. I then introduce the hospital context and describe how the architecture of surgical suites interacts with the information displayed on large public displays to shape communication and coordination within and between nursing, surgical and anesthesia staff.

1.1 Architecture and Interaction

The term *architecture,* as I use it in this dissertation, refers to the built environment.[2] Architecture involves many levels of analysis, from objects in a room or hallway, to the layout of a building, to a complex of buildings, and beyond. I focus on the architecture at the *building level* and the *local level*. The *building level* refers to the configuration and location of rooms and hallways. Important factors at the building level are the adjacency of spaces, connectivity between spaces, and resulting indoor traffic patterns. The *local level* refers to the configuration and location of furniture and objects in rooms and hallways. Important factors include whether there are places for people to pause and to access objects.

Extensive research on the influence of architecture in organizations has shown that the built environment shapes where people move and pause, where they place information they want others to see, and how much interaction people have (e.g., Allen, 1977; Hatch, 1987; Kraut, Fish, Root, & Chalfonte 1990; Sommer, 1969). At the building level, physical proximity increases the quantity of communication among co-workers in office buildings (Allen, 1977). In a research organization, smaller distances between researchers' offices predicted a greater likelihood that researchers would co-author

[1] In some surgical suites the whiteboard that displays the surgical suite schedule is called the "operating room (OR) schedule whiteboard," or the "OR schedule board." Throughout the dissertation, I use the term "whiteboard" to mean a whiteboard used to display the surgical suite schedule. I use the generic term "schedule board" to include "whiteboards" and "electronic schedule boards" used to display the surgical suite schedule.
[2] More generally, architecture refers to the relationship between parts of a complex object or system.

papers, presumably because they were more likely to engage in opportunistic and spontaneous conversations and discover mutual interests when they were close by (Kraut et al., 1990). In housing complexes, a smaller distance between apartments and location of staircases increased interaction opportunities, which in turn was associated with friendship and influence (Festinger, Back, & Schachter 1950). In that study, even when neighbors were close in distance to one another, visual barriers such as walls reduced opportunities for eye contact and initiating interaction. It is possible to be too close. In one study of an open office plan, office walls and doors encouraged interaction because they created a private territory that allowed for confidential communication and reduced interruptions on others (Hatch, 1987).

At the local level, the arrangement of a physical space and the objects in the space affects interaction. The concept of "synomorphy" assumes that the shape and design of the places where people interact inevitably shape their dynamics: for good and for bad (Barker, 1968). For example, how people position their office desks is an important factor in determining visual co-presence and the amount of interaction (Hatch, 1987). Visitors in a waiting room affiliated more when easily understood conversation pieces such as artwork decorated the room (Meharabian & Diamond, 1971). Another related concept is territoriality. People's territory can be marked out with furniture and decorations. Personalizing an environment marks a territory; it can discourage vandals and encourage strangers to interact in a friendly manner (Vinsel, Brown, Altman, & Foss, 1980).

The arrangement of spaces and displays mediates not just interaction but also people's access to information and objects. Retail stores size passageways to allow both circulation space and activity zones for customers standing or seated around counters and displays (e.g., Neufert & Neufert, 2000; Panero & Zelnik, 1979). Reduced sales result when others passing at close distance interrupt buyers looking at a product display (Underhill, 1999). The adjacency of in-store product displays (Chevalier, 1975) and signs (Armata, 1996) influences buying behavior by reminding people of related needs. For example, stores place briquettes near barbecue sauce and socks near displays of shoes.

Furniture shape and location limit the positions in which people can place themselves. In dyadic interactions there are essentially four positions people can place themselves in relative to one another: face-to-face, at right angles, side-by-side, and back to back. Sommer (1969) showed that choice of seating location depended largely upon the type of task. Two people who are co-acting rather than interacting (e.g., sitting at the same table working on different things) choose seats that are not face-to-face. When collaborating or having an informal conversation, people prefer to sit at right angles, whereas for competitive tasks, they tend to sit opposite one another. Thus, the physical arrangement of benches, chairs, and tables can determine whether people are able to interact comfortably.

1.2 Architecture and Information Technology

The architecture of a building affects people's access to information sources. The space among people engaged in an interaction defines an area not available for others to stand in or walk through (Goffman, 1963). Crowding limits people's choice of position and thus access to things and other people.

Modern architecture may contain both information technology and people engaged in cooperative work, using technology. Schmidt and Bannon (1992) introduced the concept of *common information spaces* to describe the activities and cooperative work that may emerge around shared computer-based information resources. People create common information spaces by discussing and negotiating the meaning of shared objects and information. Common information spaces can be virtual (e.g., an online database) or physical (e.g., an airline control room; Bannon & Bødker, 1997). In hospitals I studied physically-situated common information spaces around scheduling boards and nursing control desks. I studied how the architecture of hospital buildings is associated with the success or failure of these spaces.

The building level configuration and local level configuration of building architecture may affect the creation and maintenance of common information spaces. At the building level, when information artifacts and people are in different physical locations, people must travel or use technology to create (and maintain) a common information space. Bertelsen & Bødker (2002) observed that wastewater plant workers "zoom with their feet" to gather necessary information throughout the plant. At the local level, the arrangement of displays depicted on computer screens, the placement of large displays, notes, and charts, and information spoken aloud may support or inhibit the creation and maintenance of a common information space (e.g., Suchman, 1997; Goodwin & Goodwin, 1996). Whittaker and Schwarz (1999) compared the effects on task scheduling of physical wallboards vs. calendaring software in software development teams. The public nature of the wallboard promoted group interaction and collaborative planning around the board. The large size, central location, and people's ability to change information on the wallboard encouraged them to take greater responsibility, to feel more commitment, and to update information more rapidly. Despite these benefits, the wallboard fell short on several other dimensions such as distribution of information, complex dependency tracking, and versioning. Digital calendars enabled wider distribution of information, and better control of dependencies and versions.

The location and visibility of displays are associated with people's interaction with the display. Researchers found that mounting public large displays high on the wall discouraged viewers' engagement with the displays (Huang 2007; Huang, Koster & Borchers. 2008). Huang et al. (2008) suggest that system designers consider the position and context of the large display in the design phase rather than after deployment.

To create and maintain a common information space around large wall displays, people position themselves at different distances from the display and from one other. Rogers and Rodden (2003) describe the area around large displays as composed of three activity areas: the direct interaction activity area nearest the display; the focal awareness activity area a medium distance from the display; and the peripheral awareness activity area furthest away. People move from peripheral activities to focal awareness activities, overcoming commitment thresholds before interacting with the system. Hawkey et al. (2005) found that being close to a display makes direct input interaction easier, but compromises effectiveness of collaboration in using the board. Being close to a display also reduces opportunities to establish eye contact and initiate interactions with others, creating a tradeoff. A few studies have examined individual preferences for the placement of large displays and have looked at human factors. For example, Wigdor et al., (2006) found that people prefer a display location and input device arrangements that give them personal comfort more than they want an uncomfortable arrangement with better performance. Su & Bailey, (2005) determined that large displays should be separated on a horizontal plane up to 45 degrees, should not be placed behind people, and if that position is needed, the displays should be offset relative to their users.

1.3 Limitations of Prior Work

As the previous sections make clear, many studies show how the physical environment mediates social interaction, and how information technologies can support collaboration and coordination, and they describe social aspects of large displays. Surprisingly little research examines how aspects of the architecture and information artifacts together shape cooperative work. In particular, I have found no studies that specifically focus on how the architecture surrounding information artifacts such as large displays is associated with group coordination.

Researchers have looked at information display placement in particular domains such as conference rooms (e.g., Panero & Zelnik, 1979), control rooms (e.g., Noyes & Bransby, 2001), movie theaters and museums (e.g., Neufert & Neufert, 2000), and roadways (e.g., US GPO, 1980). However, where to place large displays in critical complex environments, such as surgical suites in which workers move from one specialized patient care space to the next, is an unexplored area. Largely understudied is how the architecture at the building level and at the local level, including the location of artifacts, together affect interaction, use of information, and coordination.

1.4 Research Setting: Hospital Surgical Suites

Previous research has examined how dimensions of the architecture (especially proximity and visual access, and the placement of displays) influence informal interaction and coordination through face-to-face discussion. Much of this work has been conducted in comparatively stable office environments. Surprisingly little research examines how the detailed design of the physical environment, including the physical layouts of rooms and corridors and the placement of multiple information artifacts, supports or hinders interaction and information exchange for ongoing coordination in hospitals. I found very little research on the physical environment of workers who are mobile and who must coordinate work across groups, time, and place, as they must do in hospitals.

In surgical suites, surgeons, anesthesiologists, and surgical suite nurses constantly coordinate a complex web of information and tasks (Bardram & Bossen, 2005a; Bardram, 2000; Ren, Kiesler, Fussell, & Scupelli, 2007; Strauss Fagerhaugh, Suczek, & Wiener, 1985; Xiao, Lasome, Moss, Mackenzie, & Faraj, 2001). Ongoing coordination is complex for four reasons. First, the surgical suite schedule changes unpredictably to accommodate incoming emergency surgeries, medical complications, and surgery cancellations. Constant coordination allows adapting the schedule to accommodate staff workload and resource availability. Second, interdependent task coordination is necessary across professional roles and groups to achieve multiple goals including efficiency, quality of care, and staff and other resources (Bardram, 2000). A sudden surgery cancellation risks wasting operating room time, resources, and staff time unless a new surgery replaces the cancelled one. Coordination is necessary to muster the appropriate staff members for the new surgery and deliver the correct equipment and surgical supplies to the operating room. Staff members from different specialty groups negotiate how they will adapt to the new schedule; these groups may have different understandings of what is needed (Strauss et al., 1985), and personal agendas and interests that can complicate communication and coordination (Reddy, Dourish, & Pratt, 2001; Ren et al., 2007). Staff shortages also complicate coordination. Third, interdependent work is coordinated across time. Temporal coordination in the surgical suite consists of three sub-activities: scheduling to create a plan over time, synchronizing across groups, and estimating resources and workload to determine how much time to dedicate to each activity (Bardram, 2000). Fourth, coordination across the physical environment is necessary because staff, patients, equipment, and information are distributed and move physically through specialized hospital environments (Bardram & Bossen, 2005b). Thus, the physical location and context of people and information artifacts influence coordination across space and time.

People use oral communication to coordinate in hospitals (Moss & Xiao, 2004) but there is too much to remember and mistakes can be fatal. Therefore, hospitals are rife with information artifacts that support coordination across tasks (Nemeth, 2003). People use charts, printed schedules, automated alarms, computer displays, and large display patient status boards (Xiao et al., 2001; Moss & Xiao, 2004; Bardram et al., 2006).

Traditional hand-written whiteboards and, increasingly, electronic whiteboards serve as shared tracking systems (Xiao et al., 2001; Bardram et al., 2006; Hu et al., 2006).

One of the most important artifacts in the surgical suite is the scheduling whiteboard, a large display on a physical white board hung on a wall (Figure 1-2). People write on the board using colored erasable-ink markers or they stick information strips or magnets to it. The whiteboard displays the surgical suite schedule and related information such as available staff, patient locations, patient precautions, and other messages for the staff (Xiao et al., 2001). Surgical suite staff members use the whiteboard to learn their assignments at the beginning of the shift. They also rely on the whiteboard throughout their shift to track ongoing cases and overall workload in the surgical suite.

The whiteboard provides a temporal plan and meter that facilitates synchronization of schedules and people (Bardram, 2000). It reduces the burden on staff to remember all ongoing surgery cases and the information pertaining to each case (Xiao et al., 2001).

Whiteboards and paper records that people carry with them may contain the same information, but the whiteboard is a shared resource for coordination. That is, the whiteboard not only informs groups but also serves as a working script for negotiation and decision -making by surgeons, anesthesiologists, nurses, and other staff. It allows sufficient detail for people to coordinate their work, while allowing flexibility (i.e., entries can be erased and updated) (Bardram, 1997). The charge anesthesiologist, the charge nurse, and surgeons use the whiteboard as a reference and a shared problem space during face-to-face discussions (Xiao et al., 2001). The surgical suite whiteboard also “re-represents” information in the computer system, allowing people to move information around and to add relevant information, such as break assignments, that are not contained in the computer scheduling system (Bardram, 1997). Gathering around the surgical suite whiteboard, members of the team can discuss proposed plans while consulting the overall schedule (Xiao et al., 2001). The charge anesthesiologist, the charge nurse, and, in some cases,surgeons, are the main people responsible for major scheduling decisions during the day such as adding/cancelling cases or opening/closing an operating room. They are the main source of the dynamic information added to the whiteboard during the day. The staff person or persons who directly update the whiteboard varies from hospital to hospital (Gilbert, 2002). Whiteboard updaters may be the charge anesthesiologist or charge nurse, but might also be a clerk, another nurse, or a certified registered nurse anesthetist (CRNA) designated as whiteboard coordinator. In some surgical suites, nurses update the whiteboard, mainly with information pertaining to nurses.

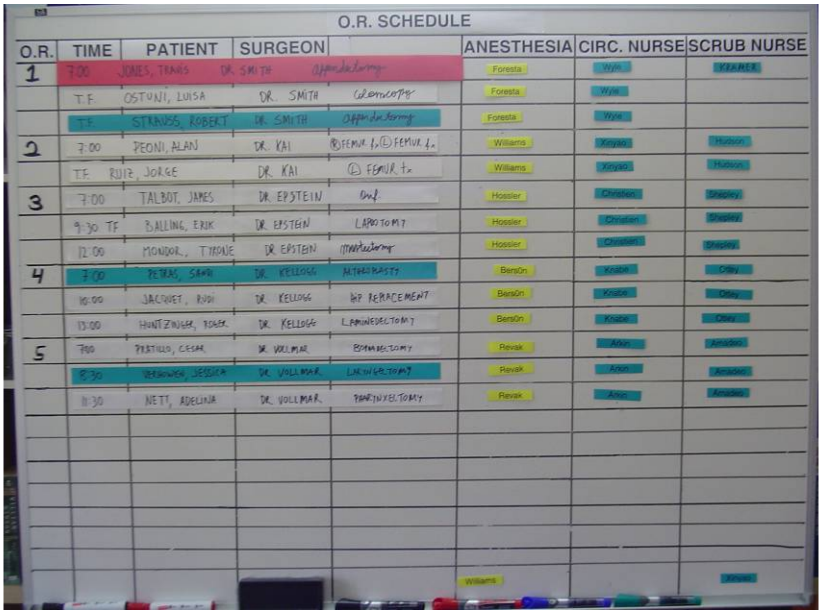

Figure 1-2. A schedule board for a surgical suite with five operating rooms; (left) Room number and patient strips; (right) staff name magnets. Anesthesia staff is on the yellow magnets, and nursing staff in blue magnets. (top left) The red patient strip indicates an emergency surgery case. The white patient strips indicate a regularly scheduled surgery; blue patient strips indicate a surgery case added to the schedule on the day of surgery.

Another critical source of information in hospital surgical suites is the surgical suite nursing control desk.[3] Originally, the control desk's central role was to insure that only staff could access the sterile areas surrounding operating rooms. In today's surgical suite, the control desk nurses also have a coordination role. They manage the moment-to-moment schedule for the surgical suite, including scheduling emergency and new "add-on" cases, coordinating day-of-surgery support services, managing work assignments related to transport of patients and specimens, equipment, supplies, and medical equipment on demand for delivery to the surgical suite, and adding information into a computer schedule to generate preference lists for necessary surgeon-specific equipment. The control desk therefore plays a critical coordination role because staff go there to find

[3] Nursing stations, front desks, and control desks are common in healthcare centers. I focus on the "surgical suite nursing control desk." It is also called "surgical suite front desk" or the "OR control desk." I use the term "control desk" to mean "surgical suite control desk," "surgical suite front desk" or "OR control desk."

out about assignments, patient transports, specimen samples, and the surgical suite schedule.

Coordination workers at the control desk and those who update the whiteboard are key information sources and the go-to people on whom others depend. The whiteboard and control desk also may have an important relationship that affects coordination. For instance, in some hospitals, changes in schedules, patients, rooms, and staff assignments that occur at the control desk need to be updated on the whiteboard (if the whiteboard carries that type of information). Different staff may assume the responsibility to update the whiteboard in different surgical suites. For instance, in some surgical suites, anesthesiologists update the whiteboard, mainly with information pertaining to anesthesiology. Negotiations around the whiteboard can send people to the control desk, to request changes to room assignments, which then require the whiteboard updates. The linkages between the control desk and the whiteboard in some hospitals are much stronger than in others.

1.5 Concept of Information Hotspots

From the previous discussion, I develop the concept of information hotspot. An information hotspot is a physical place where three critical needs of ongoing coordination can be met: (a) people congregate to receive and provide information, (b) public displays offer up-to-date information, and (c) people having or assuming a coordination role are present to answer questions, resolve conflicts, and keep information up-to-date. The concept of information hotspot helps to identify common information spaces in which people interact and coordinate work within and across groups. In the surgical suite, information hotspots emerge around the scheduling whiteboard and the nursing control desk. Because of their importance to ongoing coordination, I focus on the architecture of these information hotspots, and ask what dimensions of the physical environment make them conducive to coordination.

I distinguish information hotspots from social hotspots, information query locations, and broadcast locations. Social hotspots include break rooms, cafeterias, copy machine rooms, water cooler locations, or hallways where people congregate during breaks or between tasks. However, social hotspots do not contain information artifacts or people with a coordination role. Information query locations are places where information providers answer questions but people do not congregate and do not coordinate their work. Broadcast locations display information and work unit status, but do not become information hotspots unless the information is up-to-date, people congregate there, and coordination workers are available to answer questions and resolve conflicts. Broadcasting information alone does not clarify questions that arise or resolve conflicts.

Previous research regarding the influence of the architecture on social behavior, cited above, led me to look for at least five different ways that the architecture might affect the emergence of an information hotspot. Closer physical distances, between information sources and where people work or walk, should be associated with the emergence of information hotspots for people to coordinate (e.g., White, 1986). Second, the visibility of information sources from where people are working or walking should aid coordination around these sources (Turner, Doxa, O'Sullivan, & Penn, 2001). Third, crowding, or insufficient space, or information sources placed in inconvenient locations, should inhibit coordination around these sources (Panero & Zelnik, 1979). Fourth, the connectivity and the centrality of where an information source is located will be associated with the number of people there (Hillier, 1996). Fifth, the geometric shape of the control desk and its surrounding space will determine whether people can speak comfortably with one another (Panero & Zelnik, 1979). For instance, a U-shaped control desk counter, because it allows people to speak at a 45 degree angle, should be conducive to cooperative conversation (Sommer, 1969).

Surprisingly, current design and construction guidelines for healthcare buildings do not mention where and how to place information displays or how to configure the spaces that will host these displays and the surgical suite nursing control desk. The guidelines are limited to specifying that the control station should be “located to permit visual observation of all traffic into the suite” (AIA, 2006), emphasizing its original access control role rather than the coordination role the control desk has assumed in many modern hospitals.

Hospitals place nursing control stations and surgical suite whiteboards in many different locations (Gilbert, 2002). For instance, some hospitals place a large whiteboard in a hallway through which all staff members pass leading to the surgical suite sterile corridor. Others place their whiteboards in locations accessed almost exclusively by one group, such as anesthesiologists. Still other hospitals have experimented with distributed whiteboards that provide patient information not only to staff but also to visitors in waiting rooms. As I shall show, these decisions have consequences: The placement and spatial relationship of the surgical suite whiteboard and the control desk are an important design decision that affects the coordination of work in the surgical suite unit.

1.6 Dissertation Contributions

The contributions of this dissertation are:

(1) A detailed understanding of how the architecture and displayed information are associated surgical suite coordination activity, derived from two long-term observational studies of four surgical suites. I detail how the architecture and displayed information are associated with coordination activity.

(2) The concept of *information hotspots*, developed in the course of conducting field research. As I discuss in detail in Chapter 4, information hotspots are a location where people can meet to exchange information, public displays offer up-to-date information, and coordination workers manage and maintain information. The concept of *information hotspots* provides a theoretical framework to help analysts and designers to deal with information technology enhanced physical environments. The information hotspots concept links the characteristics of the surrounding environment, information artifacts, and social behavior to cooperative work outcomes.

(3) A set of design principles and design guidelines for surgical suite large display positioning. I developed these design tools by applying the information hotspots framework to the data from the observational studies. The design principles and design guidelines explain how to position surgical suite schedule boards to maximize impact.

(4) An evaluation checklist for surgical suites useful to assess existing surgical suites and surgical suite design alternatives. Architects, large display developers, and surgical suite decision makers may benefit from this evaluation checklist.

(5) A three level modular design strategy for existing surgical suites; the strategy ranges in implementation effort. (a) Minimum implementation effort involves moving only existing information artifacts. (b) Medium implementation effort involves introducing technology to overcome current limitations. (c) Maximum implementation effort involves changing the physical environment by moving walls, etc.

(6) A survey to surgical suite directors in hospitals nationwide to study the linkages between architecture factors, information available, and workplace characteristics and information exchange and coordination outcomes.

1.7 Dissertation Overview

The rest of the document is as follows: In Chapter 2, I present the Pennsylvania field study of whiteboard use in two local surgical suites of a large medical center. I observed interactions around the whiteboard over 185 hours over six months. As implied by the discussion above, I discovered while collecting data that another factor in coordination was the relative location of another central source of information—the nursing control desk. In Chapter 3, I present the Maryland field study of whiteboard use and nursing control desk in two surgical suites in a large medical center. I observed interactions around the whiteboard and control desk over 110 hours over two months. I explicitly examined the architecture of the built environment of scheduling whiteboards and nursing control desks, and their relationship with one another, in two different surgical suites. In both studies, I found the spatial relationship of the whiteboard and control desk are as important as their location independent of one another. Chapter 4 presents design principles, design guidelines, and three level modular design strategies, based on these two field studies. I discuss some limitations to the generalizability. In Chapter 5, I describe a survey conducted with surgical suite directors nationwide. The survey questions asked about the linkages between architecture, information, and workplace setting on information sharing and coordination outcomes. In Chapter 6, I summarize findings, list limitations, and discuss future directions.

Chapter 2: The Pennsylvania Field Study

The study reported in this chapter investigates the role of location of and distance between the whiteboard and control desk. I chose to study the whiteboard and control desk because they are central information hubs for surgical suite staff.

As described in Chapter 1, in surgical suites the whiteboard represents the surgical suite schedule, available staff, patient locations, patient precautions, and other messages for the staff (Xiao et al., 2001). The nursing control desk is a central coordination hub for the surgical suite. Workers manage emergency cases and coordinate day-of-surgery support services for patients, surgeons, nursing, and families. They coordinate work assignments related to transport of patients and specimens, equipment, supplies, and medical equipment on demand for delivery to the surgical suite. Typically, they schedule surgical add-ons manually, and input add-ons into computer schedule to generate preference lists for necessary surgeon-specific equipment. The control desk plays a critical coordination role because its workers keep detailed records of transports, specimens, and the surgical suite schedule.

Prior literature leads me to believe that the distance between the whiteboard and the control desk would be associated with differences in coordination behavior and communication patterns. Thus, I decided to observe coordination behavior around the whiteboard.

2.1 Field Study Setting

The two surgical suites in Pennsylvania differed in physical environment at the building level and the local level. I observed two surgical schedule whiteboards in a large medical center. I refer to the larger surgical suite unit with 25 operating rooms as “XL Surgical Suite” and the medium sized surgical suite unit with 14 operating rooms as “Medium Surgical Suite” (in chapter 3, I refer to the Maryland surgical suites as Large Surgical Suite and Small Surgical Suite). The two Pennsylvania surgical suites had many common features —medical staff consisting of attending anesthesiologists, anesthesia technicians, surgeons, and nurses (some worked at both surgical suites), surgical scheduling staff, and the same surgery scheduling service.

In the XL Surgical Suite (Figure 2-3) the whiteboard was located in a hallway around the corner from the control desk whereas in Medium Surgical Suite (Figure 2-2), the whiteboard was in the same space, and adjacent to the control desk. Anesthesiologists frequently passed by and looked at the whiteboard, so I expected the mutual visibility of the whiteboard and control desk to influence informal interaction between anesthesiologists and charge nurses.

The two units differ in their surgical specialties. XL Surgical Suite, a level one regional trauma center, specializes in cardiothoracic surgery, organ transplantation, neurovascular surgery, orthopedic surgery, critical care and trauma services, and neurosurgery. These tend to be serious, long, and comparatively high-risk surgeries. Medium Surgical Suite specializes in small bowel and liver transplantation, orthopedic, and ambulatory surgery. With the exception of the transplants and some kinds of orthopedic surgery, the surgeries at Medium Surgical Suite are serious but take less time than those at XL. During our study, on a regular workday, XL Surgical Suite scheduled 40 to 50 surgeries and Medium Surgical Suite scheduled 30 to 40 surgeries. XL Surgical Suite had more rooms and scheduled cases, but on average fewer cases per room as compared with Medium Surgical Suite.

2.2 Method

I collected data from June to December 2005. I spent 185 hours over a period of 6 months observing activity around XL Surgical Suite and Medium Surgical Suite’s scheduling whiteboards. To collect a representative data sample, I conducted 18 field visits in each hospital on different days of the week and at different times of day. To assess the coordination load I counted the number of scheduled rooms and the numbers of cases listed on the whiteboard at around 7 AM.

I recorded activities while at the whiteboard (e.g., look at whiteboard, update whiteboard, make phone call, leave the whiteboard, etc), wrote a summary of what people said while at the whiteboard, and described their conversation partners. Each event recorded was time stamped. I began daily observations by counting the number of ORs staffed on the whiteboard and the number of cases posted for each room. All field notes were hand written due to patient privacy concerns. Within a day of field observation, the observer typed field notes verbatim and added details to explain the context surrounding the recorded events.

I developed a coding scheme through careful reading and synthesis of the field notes (see Table 2-1). I coded all field notes collected in three passes. First, I identified who was at the whiteboard; then I coded what people were doing at the whiteboard; and finally, the topic discussed. After coding the data, I analyzed the frequencies of the different activities in the different locations using Chi Square tests. Where appropriate, I used t-tests to compare the two sites.

Table 2-1. Field note coding scheme for XL Surgical Suite and Medium Surgical Suite.

Coding questions	Codes used:
1) Who is at the whiteboard?	Charge anesthesiologist (ca), anesthesiologist (a), CRNA (c), Surgeon (s), charge nurse (cn), nurse (n), other (o)
2) What are people doing?	Looking at whiteboard (look), discussing (disc), updating the white-board (up), phone (ph), other (oth).
3) What are they discussing or manipulating?	patient (pat), staffing (stf), resource (rsr), other (othr)

I collected three kinds of data to describe the physical environment of the two surgical suites: (a) I Xerox copied the fire exit floor plans; (b) I made field sketches of the area around the whiteboard and control desk; and (c) I took photographs of the setting. I used this material to create three representations for each site: a schematic floor plan, a three-dimensional model of the area around the whiteboard and control desk, and a schematic diagram of the surgical suite.

I developed five measures of the architecture: physical distance between information sources and where people are working, visibility of information sources, spaciousness of an area around information sources (allowing for conversation), connectivity (central location) of information sources, pause locations near information sources and their geometric shape. I measured distance according to the number of steps it would take someone to walk from their work location to the focal point (e.g., from the control desk to the whiteboard). I measured visibility using visibility graphs from work locations and using the isovist overlap technique (Scupelli, Kiesler, & Fussell, 2007). I measured spaciousness by the width of hallways and the area where people could stand in front of whiteboards and control desks. Connectivity refers to the links to a given location (Hillier, 1996, p. 126). I was especially interested in task-related connectivity, that is, the number of surgical task-related locations accessible from the whiteboard or control desk without opening any doors, or after opening one door. Finally, I recorded the presence and shape of furnishings (counters, benches, chairs) where people could lean or sit.

2.3 *Findings*

Physical configuration. In XL Surgical Suite, the whiteboard is located on a 5-foot wide hallway connected to the main hallway between the unrestricted area and the restricted sterile corridor, the staff lounges, and a post-anesthesia care unit (Figure 2-1).

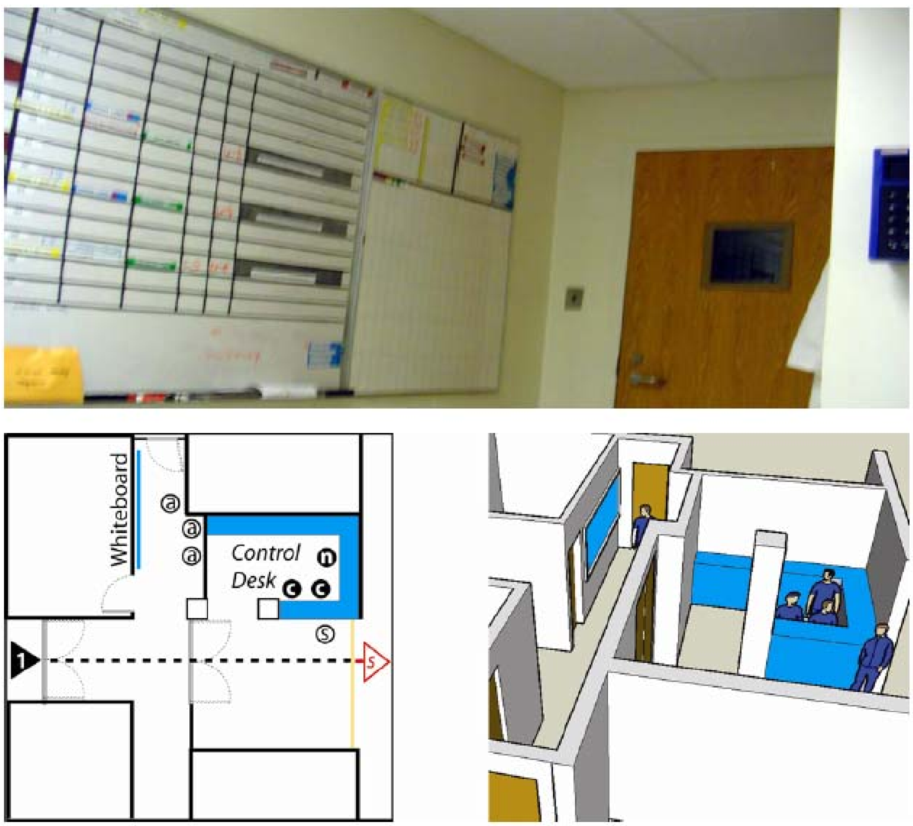

Figure 2-1. Pennsylvania field study: Photo, schematic floor plan, and 3D representation of XL Surgical Suite's whiteboard located in a side hallway off the main hallway that passes into the sterile corridor. The control desk faces the main hallway into the sterile corridor. (S indicates Route to sterile corridor inside arrow. The symbols represent *a* anesthesiologist, *n* nurse, *c* clerk, and *s* surgeon.)

All other locations (i.e., the control desk, the sterile corridor, operating rooms and the sterile work areas) are at least one or more doors away. The XL Surgical Suite control desk is around the corner from the whiteboard, separated by an automatic door, and faces onto the main hallway headed towards the sterile corridor.

In contrast, Medium Surgical Suite's whiteboard and control desk are centrally located at the intersection of three hallways and each hallway passes on one side of the control desk (Figure 2-2). This is a very connected area: The hallways lead to the patient holding area, the elevators, the unrestricted area, the operating rooms, and the post-anesthesia care unit. The whiteboard is next to the U-shaped control desk. The charge nurse sat closest to the whiteboard and the receptionist sat in the central portion facing the main hallway. To allow patient gurneys to pass the control desk, the main hallways are eight feet wide.

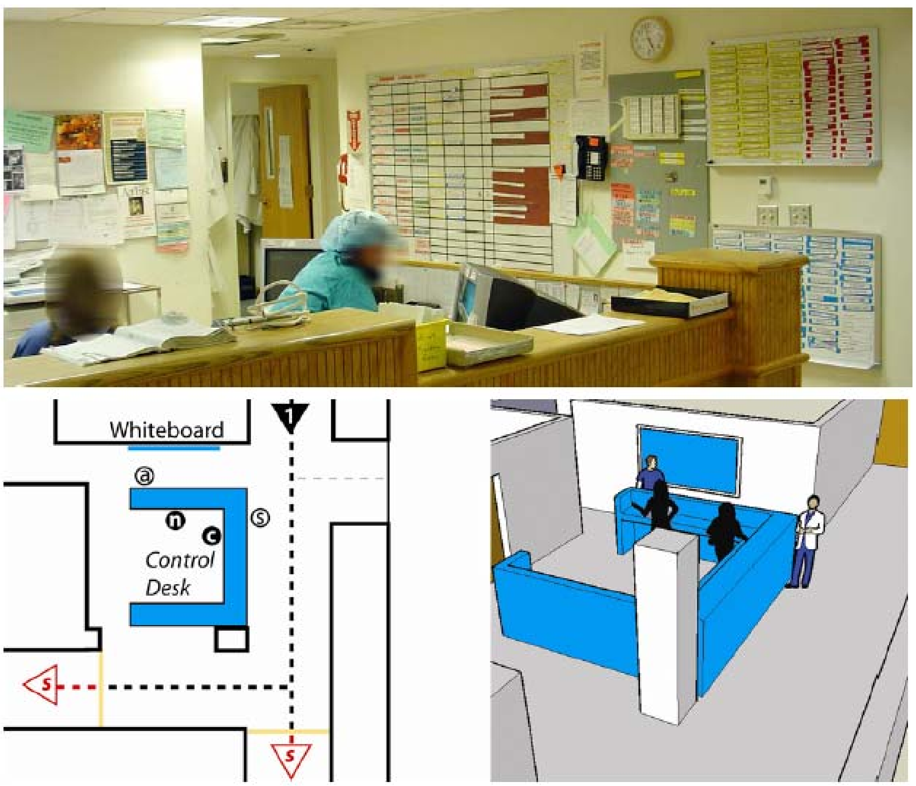

Figure 2-2. Pennsylvania field study: Photo, schematic floor plan, and 3D representation of Medium Surgical Suite's whiteboard and control desk showing receptionist (upper left) and Charge nurse (upper right). There are two paths to the sterile corridor. (S indicates Route to sterile corridor inside arrow. The symbols a, n, c, and s represent anesthesiologist, charge nurse, clerk, and surgeon.)

I analyzed the coordination needs of XL Surgical Suite and Medium Surgical Suite to determine the staff coordination load. Table 2-2 shows the observed room usage levels around 7AM when the first surgery in each room usually began, to estimate room and staff loads in each unit. I compared the morning counts of staffed rooms, posted cases, and cases per room.

Table 2-2. Coordination load of surgical suites, two field studies.

	Pennsylvania Field Study (N = 36 days, observed at 7 a.m.).		Maryland Field Study (N = 38 days, observed at 7 a.m.).	
Measure	XL Surgical Suite	Medium Surgical Suite	Large Surgical Suite	Small Surgical Suite
Mean number staffed operating rooms[a]	20.3 (min. 17, max. 24)	11.9 (min. 9, max.14)	19.6 (min. 17, max. 21)	5.8 (min. 5, max. 6)
Mean operating room usage[b]	20.3/25 (81.2%)	11.9/14 (85.1%)	19.6/21 (93.23%)	5.8/6 (97%)
Mean posted surgery cases[c]	42.8 (min. 32, max. 53)	33.7 (min. 24, max.43)	46.3 (min. 37, max. 61)	13.9 (min. 7, max. 22)
Mean cases per room[d]	2.0 (min. 1.9, max. 2.4)	2.9 (min. 2.1, max. 3.6)	2.4 (min. 1.9, max. 2.9)	2.4 (min. 1.4, max. 3.67)
Peak load (max. cases vs. rooms used) [e]	2.2	3.1	2.9	3.67

[a] Staffed operating room is a room with an ongoing surgery.

[b] Usage is determined by dividing the number of staffed rooms by total rooms in the surgical suite.

[c] Mean number of surgeries scheduled at 7AM.

[d] Cases per room is determined each day by dividing scheduled cases by operating room usage.

[e] Peak load is maximum number of cases divided by the rooms staffed that day. The peak load for XL Surgical Suite was 53 cases for 25 rooms, a little over 2.21 cases per room, whereas the peak load for Medium Surgical Suite was much higher, 43 cases for 14 rooms, or a little over 3 cases per room. Both XL Surgical Suite and Medium Surgical Suite used more rooms to accommodate the peak caseload resulting in a lower case per room score than in the maximum score for the cases per room cell.

XL surgical suite staffed more rooms $t(20) = 3.31$, $p=.003$, posted more cases each day $t(20) = 10.18$, $p=.0005$, but had fewer cases per room $t(20) = -4.52$, $p=.0005$. Also, the daily peak load for XL Surgical Suite was a little over 2 cases per room, whereas the peak load for Medium Surgical Suite was much higher, just over 3 cases per room. Therefore, coordination load due to room turnover was considerably higher in Medium Surgical Suite.

Coordination behavior. Due to Medium Surgical Suite's higher coordination load, I expected staff members to visit Medium Surgical Suite's whiteboard more often. To compare whiteboard visits, I determined the average number of trips staff made to each whiteboard and counted the number of people interacting there. (To normalize for differences in anesthesia staff size, I divided the number counted at each whiteboard by the number of anesthesia staff at the time.) During the study, XL Surgical Suite had on average 30 persons working in 20 operating rooms whereas Medium Surgical Suite had on average 18 persons for 12 rooms. I normalized the data by dividing the number of people counted at the whiteboards by the total days of observations and the number of anesthesia staff working each day in each hospital. (The number of posted cases per room was 2.1 (min 1.88, max. 2.38) in XL Surgical Suite vs. 2.83 (min. 2.08, max. 3.55) in Medium Surgical Suite.) On average in Medium Surgical Suite each worker made more trips to the whiteboard than in XL Surgical Suite (4.1 trips vs. 2.4 trips). Notwithstanding the higher number of posted cases, mean number of rooms, and staff on site in XL Surgical Suite the mean number of trips per person was higher in Medium Surgical Suite.

Due to the greater number of whiteboard trips, one would expect more interactions at Medium Surgical Suite, if the location of the whiteboard fostered such interaction. Medium Surgical Suite's whiteboard is located next to an information hub, the control desk. As many groups rely on information available at the control desk, it is convenient for them to use the whiteboard too. The greater number of people at the whiteboard increases the likelihood of chance encounters providing opportunities to discuss the schedule. I therefore counted staff members interacting with (reading or updating) the board (Figure 2-3). (To normalize I divided the total number of interactions by the mean number of staff working in operating rooms.) I found more interaction at Medium Surgical Suite's whiteboard. The observer noted the topic of discussion in his field notes, and coded the field notes for content (Table 2-1); there were no statistical differences in coordination conversation topics between XL Surgical Suite and Medium Surgical Suite. Hence, I use interaction between people as a proxy for coordination.

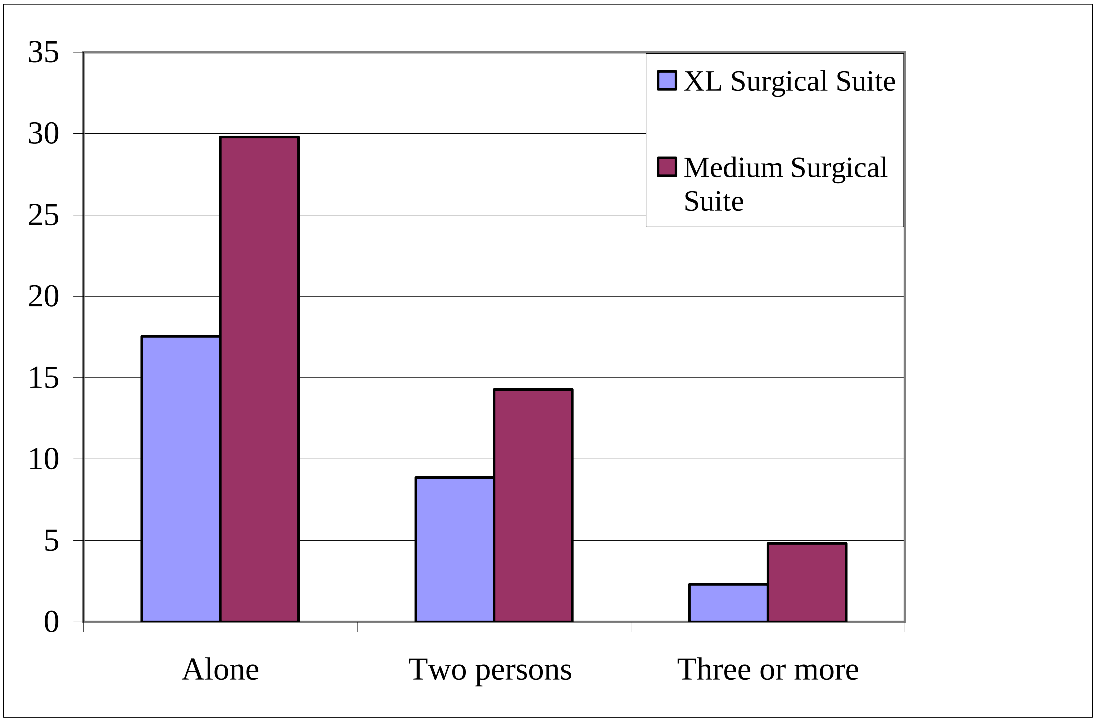

Figure 2-3. Pennsylvania field study: Interactions occurring at the whiteboard by number of people interacting. The figure regards 36 days of field observations (18 per site); each field visit was on average a little over five hours.

I also looked at interaction by role. Staffs with different roles check their assignments and the status of the surgical suite on the whiteboard. Figure 2-4 shows the average number of trips people in each role made to the whiteboard, adjusting for the number of people with the same role. In both units, the charge anesthesiologist made most trips to the whiteboard—on average 12.4 times per day at XL Surgical Suite compared with 16.7 times per day at Medium Surgical Suite. The charge nurse and receptionist stationed at the control desk interacted much less frequently at XL's whiteboard than at Medium Surgical Suite's (.06 times vs. 7.5 times). The more frequent interactions at Medium Surgical Suite support our hypothesis that locating the whiteboard near and in the line of sight of the control desk increases interaction.

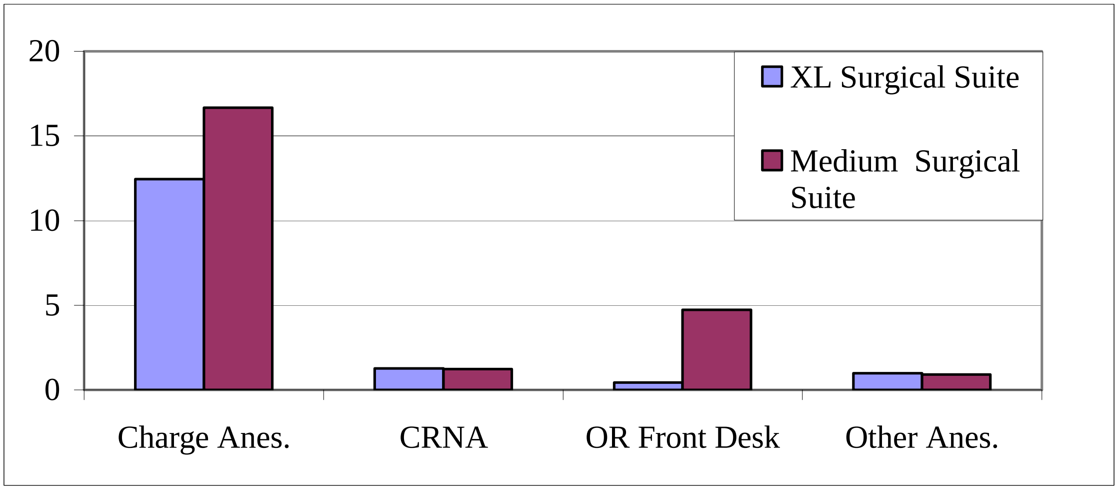

Figure 2-4. Pennsylvania field study: Number of mean trips per day to the area around the whiteboard for each role. To compare across sites, I divided the role by the number of persons that performed each role on the day of observation. The figure regards 36 days of field observations (18 per site); each field visit was on average a little over five hours.

Distance and visibility barriers were associated with congregating less at XL Surgical Suite. This may explain in part who interacted with the charge anesthesiologist at the whiteboard. Figure 2-5 shows the whiteboard co-presence patterns of the charge anesthesiologist by interaction partner. At XL Surgical Suite, the charge anesthesiologist interacted at the whiteboard with control desk staff fewer times than at Medium Surgical Suite (6% vs. 25% of total face-to-face interactions by the charge anesthesiologist with others around the whiteboard).

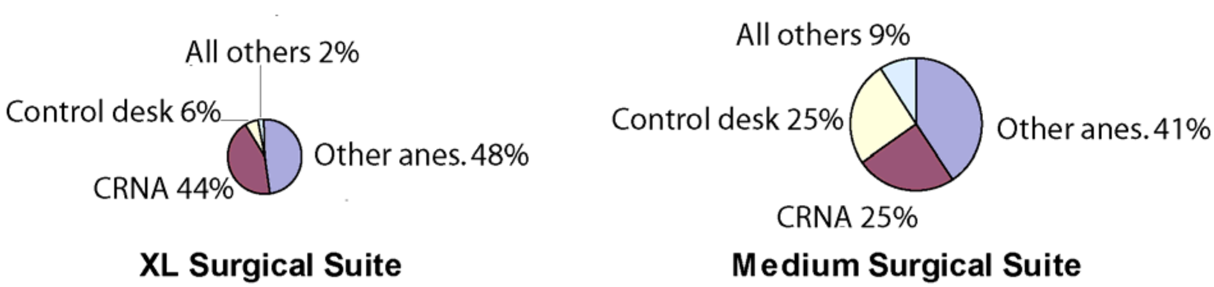

Figure 2-5. People interacting at the whiteboard with the charge anesthesiologist by role. Percentages are the interactions broken by role divided by all interactions with the charge anesthesiologist. Left, XL Surgical Suite's pie graph is scaled 68% because the charge anesthesiologist was co-present fewer times. The figure regards 36 days of field observations (18 per site); each field visit was on average a little over five hours.

Whiteboard use. Typically, the whiteboard allows access both to those co-present, and over time. One person instead, typically uses a paper surgical suite schedule at a time. Is use of paper surgical suite schedules by charge anesthesiologists associated to whiteboard use? I hypothesized that when the charge anesthesiologists used a paper surgical suite schedule, they would update their paper surgical suite schedule more frequently than the whiteboard. Fewer updates to the whiteboard would lead to more phone calls to the charge anesthesiologist. To test this idea, I compared whiteboard usage levels at XL Surgical Suite, where the charge anesthesiologists used paper surgical suite schedules in addition to the whiteboard, with those at Medium Surgical Suite where paper records were not used (Figure 2-6). I divided the counts of "whiteboard" and "phone" by the mean number of posted cases, staffed rooms, and staff in each hospital. I found little difference in phone use. At Medium Surgical Suite, I found more whiteboard use by all users and especially by the charge anesthesiologists.

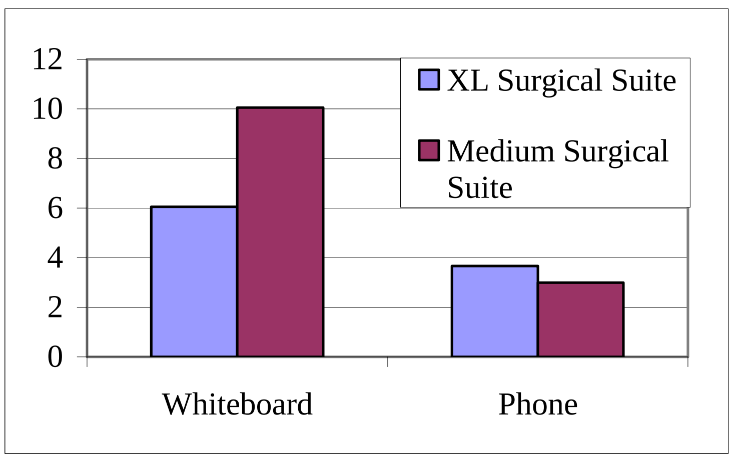

Figure 2-6. Times per day the charge anesthesiologist was seen interacting with the whiteboard and using the phone while at the whiteboard. The figure regards 36 days of field observations (18 per site); each field visit was on average a little over five hours.

The likelihood of being co-present at the whiteboard is related to the number of interaction opportunities with different groups, as well as who updated and consulted the whiteboard. Who updated the whiteboard was associated with the information displayed and updated (Table 2-3). In XL Surgical Suite, only the anesthesia team updated the whiteboard and it did not contain nursing staffing information. In Medium Surgical Suite, the whiteboard was located next to the control desk, both anesthesia team and control desk workers updated the whiteboard, and a wider variety of information was available.

Table 2-3. Whiteboard displays dedicated to the surgical suite schedule.

	Pennsylvania Field Study		Maryland Field Study	
	XL Surgical Suite	Medium Surgical Suite	Large Surgical Suite	Small Surgical Suite
Groups updating whiteboard	Anesthesia	Anesthesia, Nursing[4]	Nursing	Anesthesia, Nursing, Surgery
Display space				
Whiteboard height	4 feet	4 feet	4 feet	4 feet
Whiteboard width	11 feet	6 feet	12 feet	12 feet
Number of rows	26	15	21	6
Number columns per room	6	8	5	20
Content of information displayed				
OR nursing staff information (# columns)	0	2	2	2
Anesthesia staff information (# columns)	5	4	0	2
Surgery team information (# columns)	0	1	1	3
Patient information (# columns)	1	1	2	13

In addition to the anesthesia staffing information, the whiteboard contained surgical suite nursing staffing information and the name of the attending surgeon for each room.

[4] In this table, I refer to “surgical suite nursing” simply as “nursing.”

The anesthesia staff updated the anesthesia information columns and the patient information column. The control desk staff placed the surgical suite nursing assignments and the surgeon team information on the board. During the study, the control desk staff and the anesthesia team never updated the other group’s portion of the whiteboard.

Workers around the surgical suite whiteboard discussed the progress of cases in the surgical suite. When someone arrived from an operating room, he or she provided updates on the status of operating rooms to update the whiteboard. Newcomers learned about changes to the whiteboard as well.

2.4 Discussion of the Pennsylvania Study

The key factors of the physical environment associated with coordination opportunities in this field study were distance, visibility, and the configuration around the whiteboard and control desk. Three factors of XL’s configuration were associated with decreased interaction around the whiteboard: First, the whiteboard and the control desk were far apart. Second, the hallway with the surgical suite whiteboard was not visible from the control desk. Third, the narrow hallway limited the number of people who could see the whiteboard at the same time without getting in each other’s way. Three factors of Medium Surgical Suite’s configuration were associated with more coordination activity around the control desk and the whiteboard. First, both the control desk and whiteboard were located in a central hall that connects the non-restricted area, the patient holding area (PHA), the surgical suite sterile corridor, and the post-anesthesia care unit (PACU). Second, three hallways surrounded the U-shaped control desk allowing staff to monitor bystanders and interact with others on three sides control desk. Third, the location of the whiteboard close to the control desk allowed the charge anesthesiologist and charge nurse to discuss the schedule while looking at the whiteboard.

I proposed that the need for close coordination in a surgical suite would increase its reliance on the physical environment for supporting this coordination. Based on my field observations I do not know whether architects or administrators deliberately positioned the whiteboard and surgical suite desk to support coordination. I did find strong associative evidence that the surgical suite with the heaviest coordination load (but not the most people or patients), that is Medium Surgical Suite, had an architecture supportive of cross-group coordination between anesthesiologists and nurses.

In XL Surgical Suite, the inconvenient physical placement of the whiteboard, and its distance from the control desk, required more effort to coordinate face-to-face. People pausing at the whiteboard could not hear conversations at the control desk that might affect them. Control desk workers had to leave their chair at the control desk, and go past the automatic door, around the corner, to the whiteboard area to interact with someone from the anesthesia team. As the whiteboard area was not visible from the control desk, workers did not know if the trip was worth the effort required. Likewise, workers at the whiteboard had to call or walk over to the control desk to discuss changes to the schedule.

The comparative lack of ongoing coordination between nurses and anesthesiologists meant delays in attending to some events, and did not always know what others were doing. On two occasions observed, a control desk worker went to the XL whiteboard because the phone and overhead page system failed.

Didn't anyone hear the overhead? There is a code in the PACU, bed 7.

We have an emergency in room 1 and Dr. X is not answering the phone.

In both instances, everyone at the whiteboard and in the anesthesia lounge ran to respond to these emergencies.

In Medium, less effort was required to interact around the whiteboard and control desk because a control desk worker could interact with someone at the whiteboard without leaving his or her chair. Anesthesiologists were likely to pause around the whiteboard because they might learn about changes to the surgery schedule from the control desk workers. The whiteboard and control desk were close to the patient holding area and thus a place to pause while waiting for a patient to arrive.

The local configuration of furniture and barriers around the whiteboard and control desk influenced the visibility of people, information, and traffic. In Medium, factors at play were the geometry of the environment and control desk, the visibility around the control desk and whiteboard, and location connectivity. I observed an anesthesiologist head towards the charge anesthesiologist who was looking at the whiteboard while leaning on the control desk. I do not know why the anesthesiologist chose to go talk to the charge anesthesiologist instead of phoning or paging. However, the openness of the control desk geometry made the charge anesthesiologist visible to those arriving from the three hallways that converge onto the space containing the whiteboard and control desk. In a different incident, Medium's U-shaped control desk, and the local space configuration supported interaction among control desk workers, the anesthesia team, and surgeons. The charge anesthesiologist stood closest to the whiteboard; the surgeon on the central side of the control desk; the charge nurse sat inside the control desk. They could see each other and the whiteboard while talking.

In summary, an information source's central location, distance in relation to where people worked and had to walk, the spaciousness of areas around the information source were related to how well it functioned as a hotspot—to support people coordinating around information sources. Coordination opportunities that linked two hotspots around the whiteboard and control desk, were associated with the distance between information sources, their mutual central location, their allowing for mutual visibility, and a lack of barriers between them. The Medium Surgical Suite thus had better functioning surgical suite hotspots, not just because people congregated around the two main sources of shared information—the whiteboard and the control desk—but also because the architecture supported mutual use of the two areas. The goal of the second field study was to deepen the understanding of how the characteristics of the physical environment and information artifacts affect where people congregate, where information is with respect to groups, and how visible and accessible information is.

Chapter 3: The Maryland Field Study

In the Pennsylvania study, I predicted that the distance between the whiteboard and the control desk would be associated with different coordination mechanisms and information artifact use. In analyzing the field data, I realized that characteristics of the physical environment around the whiteboard and control desk (e.g., seating, amount of space around the board, visibility, etc.) were associated with the coordination mechanisms people used. Thus, physical distance alone could not account for the results.

To examine these other characteristics of the physical environment, I observed activity around two whiteboards and two control desks in a large medical center in Maryland, to link characteristics of the physical environment to coordination behaviors. I got the architectural drawings of the environment, measured the spaces and furniture, and made sketches of the physical environment and information artifacts.

The two units studied in Maryland differed at the building level and the local level. At the building level, automatic doors from the sterile corridor separated the whiteboard and control desk of the larger surgical suite (Large Surgical Suite), whereas the smaller surgical suite (Small Surgical Suite) the control desk and whiteboard were not. I hypothesized that in Large Surgical Suite fewer people would pause before passing through. At the local level, the furniture in the hallway in front of the whiteboard differed. In Large Surgical Suite, a control desk counter faced the whiteboard in the hallway. In Small Surgical Suite, a bench faced the whiteboard in the hallway. I anticipated the presence of furniture such as a bench as opposed to a control desk counter around the whiteboard would be associated with more pause activity and longer pause duration increased congregating activity.

The counter in Large Surgical Suite was oriented such that those interacting with control desk workers turned their back to the whiteboard and obscured the control desk worker’s view onto the whiteboard. I hypothesized that the orientation of the counter decreased visibility of the whiteboard and would encourage the use of a paper surgical suite schedule for key coordination players, as observed in the Pennsylvania study for the XL Surgical Suite.

3.1 Field Study Setting

"Large" was the larger surgical suite with 21 operating rooms, and "Small" the smaller surgical suite with 6 operating rooms. The two surgical suites were in on the same floor in connected buildings: Large Surgical Suite in a new building, Small Surgical Suite in a smaller older building.

The two units differ in their surgical specialties. Large Surgical Suite specializes in scheduled surgeries for same-day patients and in-patients. In addition to block time for scheduled cases by surgical specialty, Large Surgical Suite reserves operating room time for unscheduled emergency cases and organ transplantation. Small Surgical Suite specializes in trauma-related injuries and the schedule is more flexible given the often critical and unstable state of its patients. During my study, on a regular workday, Large Surgical Suite scheduled 37 to 61 surgeries and Small Surgical Suite scheduled 7 to 22 surgeries. Large Surgical Suite has more rooms and scheduled cases, but on average, fewer cases per room as compared with Small.

3.2 Method

I collected the data presented in the results section with the following procedures. I spent 110 hours in the field observing in Large Surgical Suite 58 hours over 41 days, and 52 hours in Small Surgical Suite over 39 days. I collected four kinds of data from mid-June to mid-August 2007. The first quantified control variables to assess the coordination load (i.e., number of scheduled surgeries, add-on cases, cancellations, etc). The second quantified pedestrian traffic passing by, and pausing at the control desk. The third tracked where people paused. The fourth kind of data regards the quantity and kind of information available around the control desk. Below is the coding scheme for these data (Table 3-1).

Table 3-1. Coding scheme for information around schedule whiteboard and control desk.

Example	Code	Date
Surgery call list July 2007	Schedule	July 2007
Department contact list	Contact	No date; but many corrections.
System failure procedures	Process	February 2005
Picnic sign-up sheet	Social	July 7, 2007.
Research Memo	Work	May 2003.

3.3 Results

Physical environment configuration. At Large Surgical Suite (Figure 3-1), the whiteboard was located eight feet away, on the opposite side of the hallway, in front of the control desk counter. The whiteboard was in a semi-public hallway off the main hallway leading to the sterile corridor. An automatic door separated the main hallway, and the control desk from the sterile corridor. The clerks and charge nurse sit behind the control desk facing the whiteboard, although the whiteboard is not legible from that distance. Staff members interacting with the control desk workers turn their backs to the whiteboard. They can passively monitor people in the control desk area but not whiteboard bystanders. The whiteboard and the control desk operate as two separate information areas.

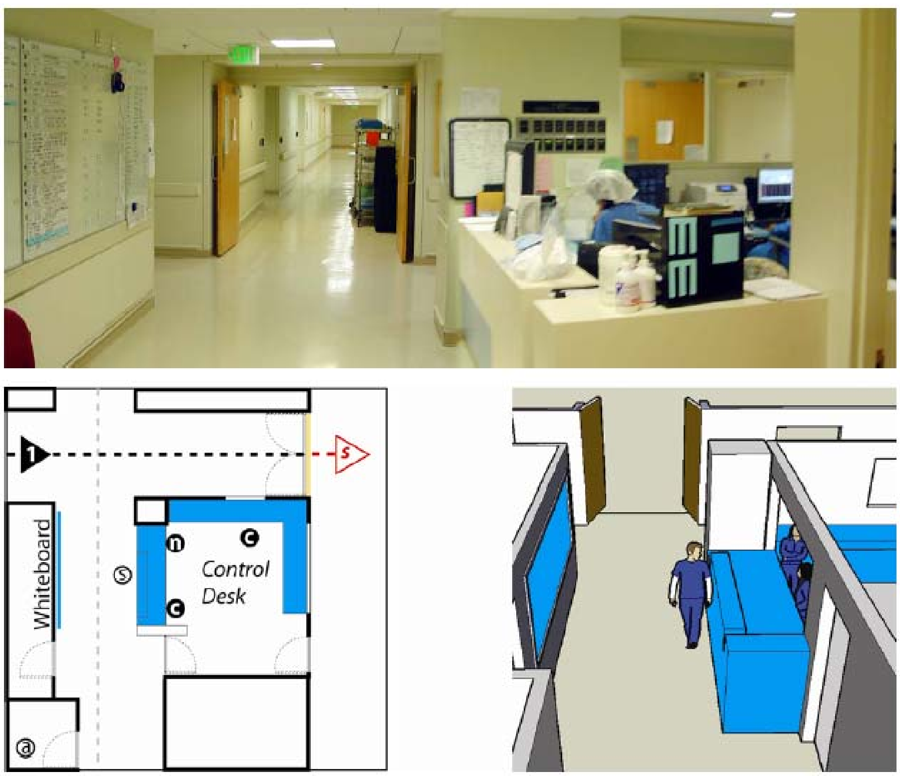

Figure 3-1. Maryland field study: Photo, schematic floor plan, and 3d representation of Large Surgical Suite's whiteboard and control desk. The charge nurse is in the photo. The whiteboard and control desk are outside the sterile corridor automatic doors. (S indicates the route to sterile corridor inside arrow. The letters in the circles represent *a* anesthesiologist, *n* nurse, *c* clerk, and *s* surgeon.)

The architect designed the hallways at Large Surgical Suite so that patient family members could reach the post-anesthesia care unit (PACU) without passing in front of the whiteboard. Unfortunately, patient family members often missed a turn and took the intended staff-only path in front of the whiteboard and the control desk. Since non-staff can see the whiteboard, privacy concerns limit the information displayed.

At Small Surgical Suite (Figure 3-2), the whiteboard is in a staff-only area requiring surgical attire. It is in the main hallway leading into the sterile corridor, past the automatic doors that delimit the sterile corridor. Located along the hallway opposite the whiteboard is an eight-foot bench; people sitting on it can read the contents of the whiteboard eight feet away. Next to the bench is the charge nurse’s wall-mounted phone. People sit or stand side by side and look at the whiteboard together.

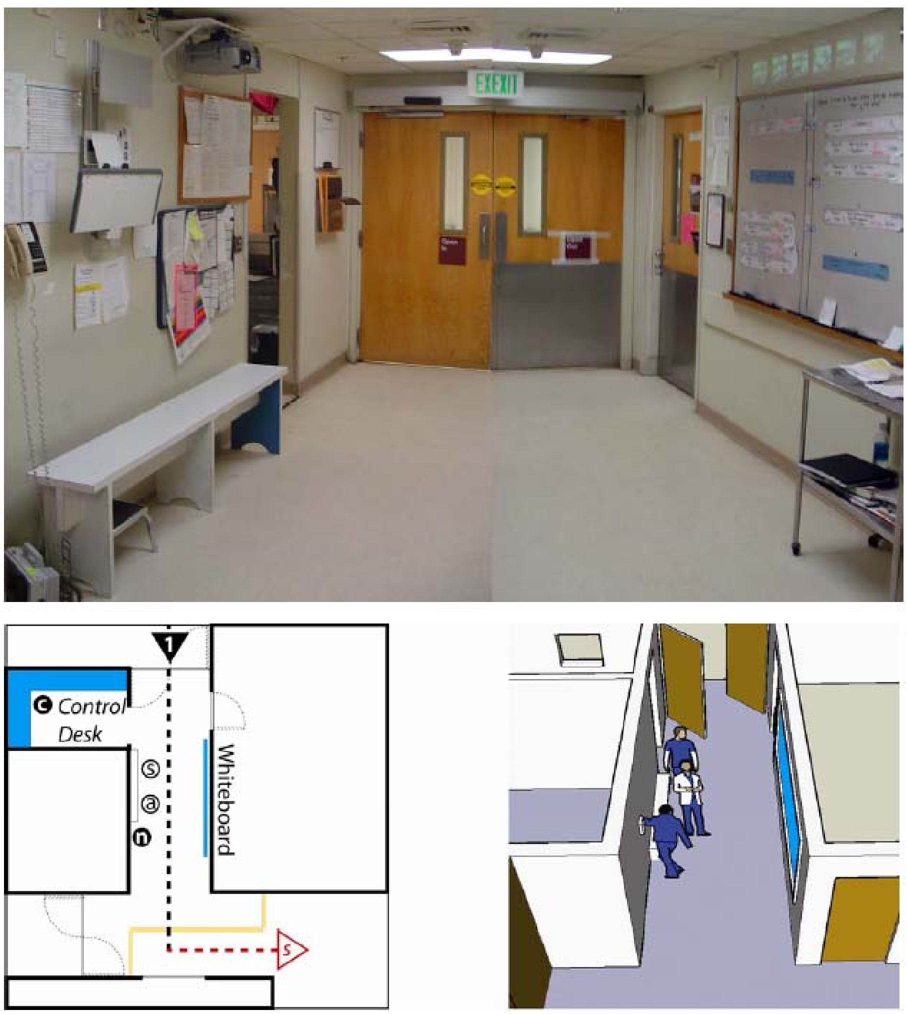

Figure 3-2. Maryland field study: Photo, schematic floor plan, and 3d representation of Small Surgical Suite’s surgical suite whiteboard. The whiteboard and control desk are inside the hallway leading to the sterile corridor. (The S inside the arrow is the path to the sterile corridor. The letters in the circles represent *a* anesthesiologist, *n* nurse, *c* clerk, and *s* surgeon.)

At both Large Surgical Suite and Small Surgical Suite, an eight-foot wide hallway separated the whiteboard and the control desk area. The units differ in the relationship with the hallway leading to the sterile corridor, readability distance of the whiteboards, and arrangement of furniture around the whiteboard and control desk.

Coordination load. Table 2-2 (in Chapter 2) summarizes the coordination needs of the two units. Large Surgical Suite had 21 operating rooms and Small Surgical Suite had 6; I compared the number of staffed rooms, posted cases, and cases per room I calculated the daily mean. When appropriate, I conducted independent sample t-tests to compare the two sites. Large, staffed more rooms $t(72) = -70.71$, $p<.0005$, posted more cases each day $t(72) = -29.24$, $p<.0005$, but similar number of cases per room staffed, $t(72) = .34$, $p=.73$. Also, the daily peak load for Large Surgical Suite was a little over 2.9 cases per room, whereas the peak load for Small Surgical Suite was much higher, over 3.67 cases per room. Therefore, the coordination load due to turnover of rooms was higher in Small[*]. The fraction of cases that are add-on cases is significantly lower at Large Surgical Suite with (26.06% versus 51.07% at Small Surgical Suite $t(47) = 7.17$, $p<.0005$. The greater ratio of add-on cases in Small Surgical Suite means that Small Surgical Suite teams must pay closer attention to changes in the surgical suite schedule throughout the day.

Coordination behavior. Although in Large, the control desk and whiteboard were located on the same hallway, those at the control desk could not read the whiteboard, and those at the whiteboard would tend to see only the backs of people talking with the charge nurse or clerks at the control desk. Furthermore, the whiteboard had limited patient information for purposes of coordination. I observed that the control desk rather than the whiteboard served as the main information hotspot. Only 30% of those who paused in the hallway congregated with others at the whiteboard, whereas nearly 60% of those who paused in the hallway congregated with others at the control desk. By contrast, Small's whiteboard was located in a convenient location right on the path of people traveling to the sterile corridor (whereas the control desk was in a side room). The whiteboard was visible from a bench where people sat to rest, put on booties, and talk

[*] The reader will note the differences in degrees of freedom regarding the total number of cases posted and the other statistics reported (i.e., average number of rooms staffed, total number of cases posted on the whiteboard as scheduled, total add-on cases, etc). I collected data from the printed OR schedule only in the latter part of the study (i.e., 26 days in Large Surgical Suite and 23 days in Small Surgical Suite respectively).

with others. The charge nurse often stood next to the wall phone, which had a long cord allowing for writing on the whiteboard. **Figure 3-3** shows that over 75% of those who paused in the hallway stood or sat with others within readable distance of the whiteboard, suggesting the whiteboard as the focal area for coordination, an information hotspot. In addition, consistent with Small Surgical Suite's higher coordination load, the number of people congregating in a hotspot is higher in Small than in Large. Figure 3-4 shows data relevant to the coordination behavior of key coordinators, indicating that they were more likely to congregate together in Small than in Large.

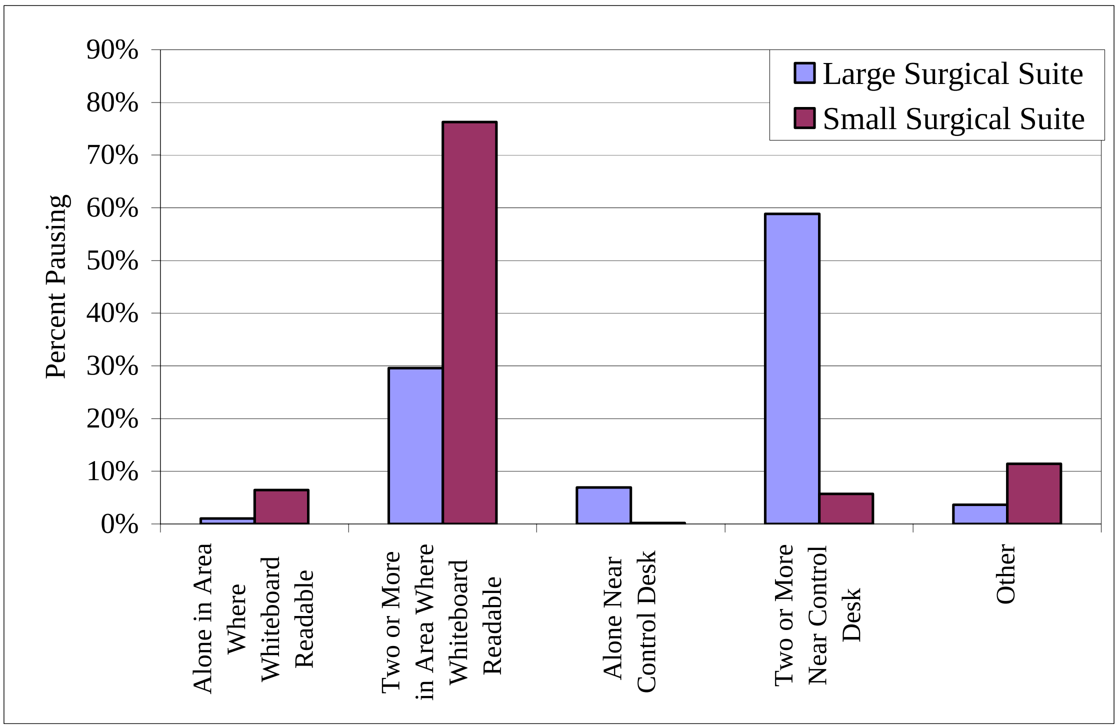

Figure 3-3. Maryland field study: Mean percent pausing alone or with others where the whiteboard was readable, near control desk, and in other remaining locations. Data regard 10 days observation, 2 hours each day starting at 7 a.m. The observer counted where people paused in the hallway between the whiteboard and control desk in each surgical suite. Percentages are the number who paused in each area divided by the total that paused.

Asynchronous Coordination. The whiteboards in both surgical suites in Maryland measured twelve feet by four feet, and presented information on "strips" and magnets that could be stuck to the display and moved around (Table 2-3). Both whiteboards were in locations off limits to visitors. However, visitors wandered past the whiteboard in Large Surgical Suite. Large used 3.5 times more operating rooms; scheduled 3.3 times more cases, and put more total information on its whiteboard (4528 items compared to the

1617 items on Small's). However, the concern for patient privacy in Large Surgical Suite led to displaying much less information per patient on the whiteboard (Figure 3-5). This limited schedule board use to coordinate surgeries and rooms. In Large, I observed that the charge nurse and clerks at the control desk updated the whiteboard comparatively infrequently whereas in Small, the charge nurse or others updated the whiteboard frequently (1.36 updates per hour versus 3.5 updates per hour). Although just across the hall, most could not read information on the whiteboard from Large's control desk.

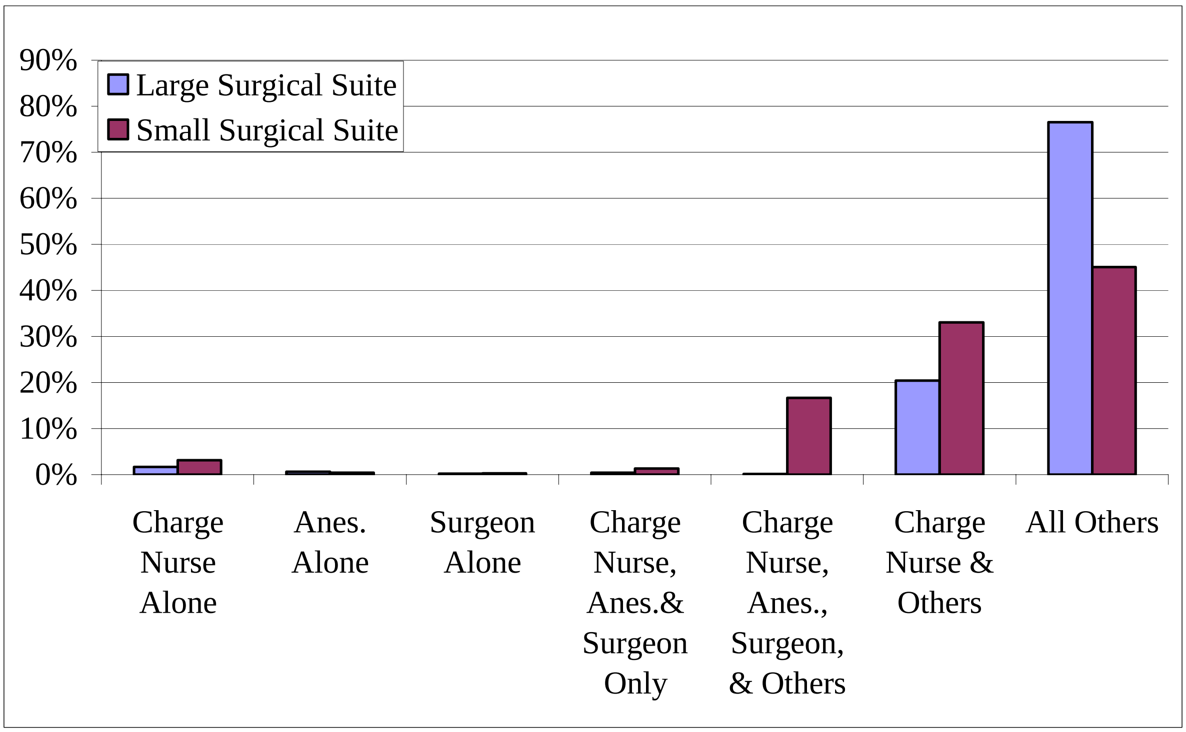

Figure 3-4. Maryland field study: Percent pausing near whiteboard or control desk by key coordination role around whiteboard and control desk. Data pertains to 10 days of observation, 2 hours each day starting at 7 a.m. The observer counted where people paused in the hallway between the whiteboard and control desk in each surgical suite. Percentages are the number who paused in each area divided by the total that paused.

Figure 3-5, upper panel, illustrates one patient's magnetic strip used on the whiteboard in Large. It measured 20 inches wide and 1 inch tall, handwriting in black marker was ¾ inches tall; from left to right: time, surgery type, surgeon's name, on the right were staff magnets indicating scrub and circulating nurse. Control desk workers only periodically updated the whiteboard. The lower panel illustrates one patient's magnetic strip used on the whiteboard in Small. It measured 30 inches wide and 3 inches tall; from left to right: the name of the patient, medical record number, surgical procedure, surgeon and resident name (handwritten in black marker 1½ inches tall), surgical equipment requests, patient status, and transport information (handwritten ½ inch tall with colored markers). On the top right, behind the magnetic patient strip was a patient call slip for patient transport; below were smaller magnets with the surgical suite nursing and anesthesia staff assignments.

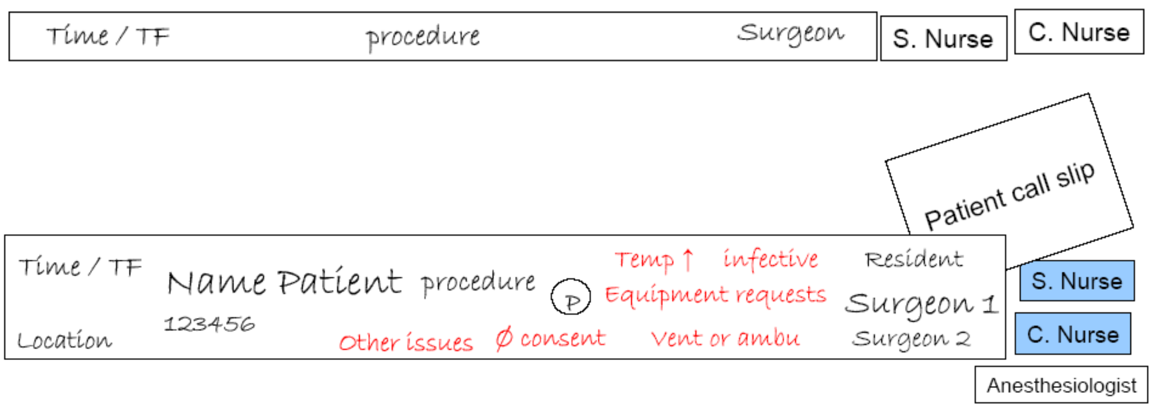

Figure 3-5. Maryland field study: surgical suite whiteboard magnet patient strip and staff magnets. Top Panel - In Large Surgical Suite, privacy concerns limit information displayed on the magnetic patient strip; next to it are nursing staff assignment magnets. Bottom Panel - In Small Surgical Suite, many pieces of patient information was on a magnetic patient strip. Next to it are the patient call slip and nursing staff and anesthesia staff assignment magnets.

Another way people coordinated asynchronously was to leave notes, messages, or bulletins on the wall next to the whiteboard, where others would see them, or at the control desk on papers, notes, or records. For instance, the charge nurse placed frequently used numbers between the operating rooms so workers could avoid a trip or phone call to the control desk.

I counted the kinds of information available in each surgical suite. In Large, information such as contact information and patient information was mainly available on demand at the control desk. In Small, staff posted contact and patient information on the wall next to the phone and around the whiteboard. To determine update frequency for posted information, I calculated how much information survived after one month (July to August). Large had less information posted around the whiteboard and control desk, a higher information survival rate, and a lower update rate.

3.4 Discussion of the Maryland Field Study

Four physical factors at Large Surgical Suite hindered coordination around the control desk and the whiteboard: First, the whiteboard was in an unrestricted hallway, and thus information it displays was limited. Second, the surgical suite whiteboard was across the hallway from the whiteboard updaters. The distance from the whiteboard and a constantly ringing phone at the control desk reduced opportunities to update it. Third, the whiteboard was difficult to read from the control desk, and thus, updaters received little benefit from updating the whiteboard. Fourth, the information access areas to the whiteboard and the control desk did not overlap.

Three physical factors would help coordination around the control desk and the whiteboard at Small Surgical Suite (Figure 3-2). First, the whiteboard and the front desk area were located inside the main corridor, thus forcing all surgical suite staff to pass in front of the whiteboard, yet there were places to pause out of the way of traffic. Second, both sides of the hallway were dedicated to displaying visual information visible to those passing through. Third, no physical barriers around the information artifacts hindered access to information. For example, the whiteboard was readable from across the hall while sitting on the bench. Workers seated on the bench could read the whiteboard because the writing was large enough.

In Large Surgical Suite, the whiteboard was not a hotspot for many reasons associated with its architecture. To update it, those at the control desk had to come around a counter and walk across a hallway. A constantly ringing phone at the control desk reduced opportunities to update the whiteboard, so it was frequently out of date. The whiteboard also was difficult to read from the control desk. Finally and perhaps most important, the whiteboard was not in a secure location where patient information could be posted freely. The control desk itself thus served as people’s main hotspot, losing this surgical suite the many advantages of a whiteboard as a place for cooperative coordination, group memory, and context for negotiation.

In Small Surgical Suite, the control desk was physically out of the way whereas the whiteboard was conducive to interpersonal interaction. Both sides of the hallway displayed visual information visible to those passing through. A phone encouraged remote communication near the whiteboard. No physical barriers around the whiteboard hindered access to information. There was space and even a bench to pause out of the way of traffic and to read the whiteboard. Work in the surgical suite entails alternating periods of high and low activity; the bench was a place to wait for patients in transit towards the surgical suite, wait for instructions or information regarding patients, and talk with the charge nurse, who was often around the whiteboard. Workers called the bench the “bus stop.”

In Small, the architecture around the whiteboard had all the elements of an information hotspot, areas for people to congregate conveniently (while they were doing other necessary tasks). People were out of the way of passersby (sitting at the bench or standing off to side at the whiteboard); the whiteboard contained up to date and comprehensive information; the charge nurse was often present, standing at the whiteboard, near the phone. The charge nurse wrote patient transport information on the whiteboard, allowing workers to anticipate and organize their workload. Even more information was on the nearby walls. Many people used wall-based information; for instance, surgeons used the contact lists.

A whiteboard with outdated information affects others: workers may prepare for the wrong surgery; and so forth. In Large, the area where one can update the whiteboard did not overlap with the updaters’ workstation. Consequently, the whiteboard across the hallway received fewer updates than the private paper printout within reach. In Small, the long cord on the phone allowed the charge nurse to update the whiteboard frequently, uninterrupted by the phone. This arrangement increased efficiency and real-time coordination opportunities, encouraged serendipitous coordination among different groups, and created an accuracy feedback loop.

The following conversation took place around the whiteboard between an anesthesiologist and charge nurse. A post-anesthesia nurse sitting on the bench overheard the conversation, and joined in with clinical details.

> *Dr. G, an anesthesiologist walks up to the charge nurse and says while pointing to the whiteboard, ‘The second case in room 6 is intubated and in the PACU.’ The charge nurse looks at the patient strip on the whiteboard and says ‘Well that means the patient is not in the unit as it says here.’ The charge nurse updates the patient strip to say “PACU.” The anesthesiologist says, ‘We should also mention that the*

patient needs a PET scan.' The charge nurse writes, 'Needs PET scan.' The PACU nurse sitting on the bench joins the conversation discussing clinical aspects of the case.

In both Large and Small Surgical Suites, workers gravitated around the information hotspots. For example, In Small the charge nurse often was around the whiteboard, sitting on the bench or standing by the phone. Rarely was the charge nurse sitting at the control desk. Likewise, in Large the charge nurse was often at the control desk and rarely by the whiteboard. In the next chapter, I describe the genesis of information hotspot concept and the creation of conceptual design tools to encourage the formation of information hotspots around whiteboards and control desks.

Chapter 4: Developing Design Guidelines

High medical costs and the need to improve efficiency, quality, safety, and privacy are leading to changes in hospital-based health care and physical environments. In the medical centers in my field studies, I observed ongoing construction, learned about past research aimed at improving efficiency, and ongoing projects. For example, in XL Surgical Suite there was a committee evaluating new anesthesia billing information systems and a system of electronic schedule boards to replace the manual whiteboard. In Small Surgical Suite, a multidisciplinary group of workers engaged in a Six Sigma process improvement study to reduce turnover time between surgeries.

Participants in the field studies often wanted to know what I learned from my observations, and what they could do to improve their work. While in the field, I hesitated to suggest particular solutions for three reasons. First, surgical suites are complex workplaces where groups with different perspectives and goals come together to deliver patient care. It is my belief that human-centered design processes[5] are necessary to develop design solutions. Second, healthcare settings have rapid obsolescence cycles driven by new medical machinery, new medical treatments, new healthcare business models, and new standards to prevent infection in the hospital. Design solutions that cannot adapt to a rapidly changing environment risk obsolescence. Third, design and construction guidelines for healthcare buildings do not mention where and how to place displays or how to configure the spaces with large displays and the control desk to support coordination (AIA, 2006).

Instead, I decided to create conceptual design tools (i.e., design principles, design guidelines, a design evaluation checklist, and modular design intervention strategies) for the location of schedule boards and the configuration of the architecture around schedule boards[6] and control desks. These conceptual design tools can support human-centered

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[5] Please refer to ISO 13407:1999, titled *Human-centered design processes for interactive systems*, for guidance on how to implement human-centered design activities throughout the life cycle of interactive computer-based systems.

[6] I refer to schedule boards in this section because I hypothesize that the design tools developed apply to both whiteboards and electronic schedule boards. I discuss the basis for this assumption in the next chapter.

design activity with surgical suite staff. From a design research perspective, I was interested in supporting surgical suite decision makers (i.e., healthcare workers, architects, and technologists). The evaluation checklist uses design principles that I extracted from the field data. Designers can use the evaluation checklist to assess the current state of surgical suites and alternative design solutions. I made the design guidelines by grouping and consolidating the design principles. For existing surgical suites, I developed three modular design intervention strategies ranging in implementation effort: (a) *minimum implementation effort* involves moving existing information artifacts; (b) *medium implementation effort* involves introducing technology to overcome current limitations; (c) *large implementation effort* involves changing the physical environment by moving walls, doors, etc.

In this chapter, I describe the information hotspots concept used to develop the design principles and design guidelines. I situate my approach in the design methods literature and detail the iterative development process for the design principles, and the design guidelines. I use the design principles to develop a tool to evaluate the current state of the field study sites. I describe the design strategy, illustrate it with concept sketches for two of the field study sites, and evaluate design alternatives. I conclude with a discussion of the limitations of the design guidelines.

4.1 The Information Hotspot Concept

The conceptual core of the information hotspots idea emerged while I was conducting pilot field observations in Maryland to tighten the focus and measures for the study. I decided to go into the field to answer a simple question: What makes large displays successful? To answer my question I looked at three examples of large displays: the current whiteboards in Large and Small Surgical Suite (Figure 3-1 and Figure 3-2) and a failed electronic display in the sterile corridor (Figure 4-1).

I decided to look at the large displays from three distinct points of view: the artifact, the people around it, and the surrounding physical environment. I listed the features of the displays in question, then the people using the large displays, and finally the surrounding physical environment. More generally, I was interested in describing the links between large displays, behavior around the displays, and physical environment.

The characteristics of the displays can explain in part the success or failure of a large display. To get started, I listed the key factors available from previous literature on whiteboards (e.g., Xiao et al., 2001; Bardram, 1997) and the human factors literature (e.g., Wickens, Gordon, S. E., & Liu, 1998). Then I went into the field and focused on the three displays. The factors that emerged from the field observations were about the information displayed (i.e., quantity, quality, update speed, accuracy, and cost to access information). Informants told me that the deployment of the electronic display failed for two reasons. First, there was not enough screen space for the complete surgical schedule to fit on the screen and thus the schedule cycled through. Surgical suite workers were under time pressure and unwilling to wait for the schedule to scroll through. Second, the display was often out of date and thus displayed the wrong information. Third, people with key coordination roles, such as the charge nurse and charge anesthesiologist, rarely congregated around the electronic display.

Figure 4-1. Disused large electronic display in the sterile corridor of a surgical suite.

The people available around the large display can explain the success or failure of a large display as well. I noticed that *who* was around the whiteboard was associated with *what information* was available on the whiteboard and in conversations around the whiteboard. People gathered around the whiteboard, received information, provided information, and discussed the schedule. Note that, someone updates the whiteboard only after the decision makers agree on the schedule change. Hearing ongoing schedule negotiations allows staff to anticipate and prepare for such schedule changes. In contrast, the failed electronic display was isolated in the sterile corridor. The failed electronic display was a place to read the posted information only. To solve a schedule problem, surgical staff had to track down the charge nurse (or charge anesthesiologist) somewhere else.

The configuration of the surrounding physical environment can explain the success or failure of a large display. In Small Surgical Suite, much activity occurred around a bench facing the whiteboard; workers sat on the bench to read the whiteboard, put booties on, and so forth. In Large Surgical Suite, the whiteboard was readable from the center of the hallway but local foot traffic kept people from congregating there. Thus, simple factors such as the configuration of the physical environment are associated with the ease or difficulty to access information on a large display.

To capture the conditions described above with respect to the success or failure of a large display, I developed the concept of information hotspots. An information hotspot is a place where three conditions coincide: (a) people congregate to receive and provide information; (b) public displays offer up-to-date information; (c) coordination workers are present to answer questions, resolve conflicts, and keep information up-to-date.

Implicit in the definition of information hotspots is the idea that people congregating in an information rich physical location promote coordination activity. The information hotspot concept helps to describe the physical environment as a variable associated with processes to create and maintain common information spaces.

My interpretation is that the architecture of the built environment around schedule boards and control desks is associated with the creation and maintenance of information hotspots that in turn facilitate coordination. Thus, in this chapter, I use the concept of information hotspots to guide the development of design guidelines for the placement and shaping of the physical environment around large displays and the control desks.

4.2 Creating Design Guidelines

Hospitals place surgical suite whiteboards in many different locations (Gilbert, 2002). Some hospitals place a large whiteboard in a hallway through which all staff members pass leading to the surgical suite sterile corridor. Others place their whiteboards in locations accessed almost exclusively by one group, such as anesthesiologists. Still other hospitals have experimented with distributed whiteboards that provide patient information not only to staff but also to visitors in waiting rooms. As I suggested in Chapters 2 and 3, these decisions have consequences: the placement and spatial relationship of the surgical suite schedule board and the control desk is an important decision that affects the coordination of work in the surgical suite. Surprisingly, however, current design and construction guidelines for healthcare buildings do not mention where and how to place displays or how to configure the spaces that will host displays and the control desk (e.g., Kobus, Skaggs, Bobrow, Thomas, & Payette, 2000). The "*Guidelines for design and construction of health care facilities*" (AIA, 2006)[7] limit the description of the control desk in surgical suites to one sentence: "A control station. This shall be located to permit visual observation of all traffic into the suite." Furthermore, there is no mention of the schedule board.

Next, I focus on design methods to evaluate the location and physical environment around whiteboards and control desks. My goal is to provide design guidelines that allow researchers, architects, surgical suite personnel and other interested parties to evaluate the current state of surgical suites and alternative design solutions.

To set the stage for my design guidelines, I first provide an overview of relevant design methods. Jones (1992) distinguishes design methods for design problems regarding systems from traditional procedures of architecture and engineering design. He mentions three design activity stages: divergence, transformation, and convergence. The divergence phase regards extending the boundary of the design situation to have a fruitful search space in which to find a design solution. The transformation phase entails making a pattern precise enough so that the results of a divergent search converge onto a single design. The convergence phase occurs after reaching agreement on the problem definition, variable identification, and goal definition. The designer then aims to reduce secondary uncertainties until only one of many possible alternative designs remains as the final solution. The three design phases are useful to understand the design process even though they are iterative in nature and do not occur in a neat linear fashion.

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[7] The American Institute of Architects will publish the next edition of the *Guidelines for design and construction of health care facilities* in 2010.

I focus on convergence phase design methods because relevant for the design guidelines. Jones (1992) lists convergence phase design methods such as checklists, selecting criteria, and ranking and weighting. Checklists are a list of questions regarding a known design problem (i.e., design the layout of a workspace). Checklists are useful for new designers on a routine design problem because they can avoid often-overlooked requirements. On one hand, designers may ignore long checklists with detailed questions because time intensive. On the other hand, short checklists with broad questions require designers to interpret the design problem.

Selecting criteria helps designers recognize an acceptable design. Jones (1992) explains that to develop selecting criteria, first, the designer determines the objectives for acceptable designs. Second, the designer establishes a measurement scale and determines a fail-safe direction relative to the objectives. Third, the designer identifies for each objective what is acceptable and unacceptable departures and then combines the individual objectives to determine a boundary on the fail-safe side between acceptable and unacceptable designs. Fourth, the designer determines the criterion and measurement that indicates if the design is on the fail-safe side of the boundary.

Ranking and weighting allows comparing a set of alternative designs using a common scale of measurement for several criteria. Jones (1992) explains ranking and weighting in six steps. First, the designer identifies the objectives to be satisfied. Second, the designer ranks objectives against each other in a matrix to establish the relative importance of the objectives. Third, to weigh the objectives, designers assign an index number that determines the importance of the objectives relative to each other. Fourth, the designer estimates the degree to which the design alternatives meet the ordered or weighted objectives. Fifth, the designer converts the estimates for the ordered or weighted objectives each into percentages. Sixth, the designer selects a design alternative. Jones (1992) cautions that ranking and weighting is a crude form of optimization when variables are difficult to measure and are not comparable. Shahin (1988) distinguishes between alternative designs with similar utility values by considering complexity to manufacture. Paired comparisons between alternative solutions and weighting criteria can suggest how to combine sub-components in new design alternatives (Ulrich & Eppinger, 1995).

4.2.1 Design Methods

The design principles and design guidelines described in this chapter rely on extended field observation. In broad strokes, the design principles guidelines result from a mixed approach from five research traditions: design methods (Jones, 1992; Ulrich & Eppinger, 1995; Cross, 2000), environmental psychology research (Sommer, 1969; Meharabian, 1976), ecological psychology (Barker, 1968), architecture research (e.g., Alexander, 1979; Hillier et al., 1984; Hillier, 1996), and computer-supported cooperative work (CSCW) theory (e.g., Bannon & Schmidt, 1989, Schmidt & Bannon, 1992 ; Xiao et al., 2001).

My goal was to create a design tool to evaluate the placement of large displays suites. How should I communicate the findings from the surgical suite field studies? Should I use design patterns—already used in the architecture, software engineering, and HCI community—or create detailed design guidelines? Design patterns by definition must apply to multiple design problems in different domains (Alexander, 1977). Design guidelines instead are specific to a design problem and domain.

I chose to make detailed design guidelines for surgical suites for three reasons. First, Plowman, Rogers, & Ramage (1995) suggest that field studies should provide detailed design guidelines because they are easier to apply and thus more useful to designers. Second, my field data is limited to four surgical suites and it is not clear that such data is sufficient to develop design patterns that apply to domains beyond surgical suites. Third, my goal is to develop the design guidelines to evaluate existing surgical suites and design alternatives by a surgical suite improvement committee (i.e., typically composed of healthcare administrators, physicians, nurses, architects, and technologists). There is some evidence that guidelines are easier for novices to learn and use than design patterns (Wesson & Cowley, 2003).

4.2.2 Guidelines Method

To establish design guidelines I worked iteratively with my field notes. I made summary tables of the sites to compare them by side. I posted pictures, cross-sections, and floor plans of the four surgical suites on a wall-sized display. Then, for each site, I listed positive and negative coordination events recorded in the field notes. For each coordination event, I wrote a summary. Under each site, I grouped the coordination events according to themes related to the physical environment. I made summary tables of the architecture, examined content on the whiteboards, and compared coordination events across sites.

Fieldwork site summaries. To isolate the factors from the physical environment that mattered in the information hotspots I made summary tables to compare the sites. I focused the summaries on particular characteristics of the surgical suites.

The whiteboard and control desk were located in hallways connected to the sterile corridor, or in secondary hallways with respect to the sterile corridor. The majority of workers headed to or leaving from the operating rooms traveled the hallway leading to the sterile corridor. Previously, I showed how the four sites differ with respect to the main hallway and the sterile corridor. In XL Surgical Suite, the whiteboard was located in a minor hallway branching off from the main hallway leading to the sterile corridor and the control desk faced onto the main hallway leading to the sterile corridor (Figure 2-1). In Medium Surgical Suite, front desk and whiteboard location form one space with the main corridor (Figure 2-2). Large Surgical Suite front desk and whiteboard were located in a hallway off the main hallway to the sterile corridor (Figure 3-1). In Small Surgical Suite, the front desk and whiteboard were located in the main hallway along the dashed arrow leading to the sterile corridor (Figure 3-2).

In Table 2-3, I compared the dimensions of the whiteboards, the type of information available on the whiteboards, and the whiteboard updaters. In Small and Medium, the greater quantity of information displayed on the whiteboard was associated more groups congregating around it. When surgical suite nursing and anesthesiology teams wrote on the whiteboard, more information available, and more interaction between groups occurred around the whiteboard. In Small and Medium the whiteboards were working documents updated frequently. In Large and XL, only one group updated the whiteboard respectively, and less information was on it; the charge nurse and charge anesthesiologist used paper records and the whiteboard was not a working document.

In Table 4-1, I summarize the integration between architecture and information in the four sites studied. In Large, the lack of a staff-only location was associated with limited information available on the whiteboard. In Small and Medium, workers entering or exiting the sterile corridor passed in front of the whiteboard and control desk; in Large and XL workers had to go out of their way to see the whiteboard. In Small and Medium, the whiteboards were readable from the control desk, and thus workers could refer to it in their discussions. In Large and XL, the whiteboards were not legible from the control desk so the control desk workers and the charge anesthesiologist used own paper schedules instead of a shared display during discussions.

The possibility of sitting around the whiteboard encouraged multiple activities around whiteboards. In Small surgical suite nurses, anesthesiologists, and surgeons used a bench facing the whiteboard inside the sterile corridor for multiple purposes (putting booties on, waiting, discussing the whiteboard contents, etc). Increased inter-group interaction opportunities resulted because of the multiple uses. In XL, instead the presence of chairs facing the whiteboard located in a secondary hallway near the anesthesia lounge was associated with mostly anesthesia team multiple use (waiting, discussing the whiteboard contents, etc.). Increased interaction opportunities within the anesthesia team resulted instead.

In Small and Medium, the physical configuration of the furniture and the shape of the space allowed to easily monitoring bystanders. The presence of others and the ability to monitor them created spontaneous interaction opportunities. Fewer possibilities to monitor bystanders in Large and XL were associated with fewer interaction opportunities.

In Small and Medium, the whiteboard was out of the way of traffic and was associated with more people congregating around it. Instead, in Large the whiteboard access area coincided with the center of the hallway. The local traffic in the hallway interfered with people congregating for longer periods in front of the whiteboard.

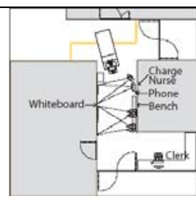
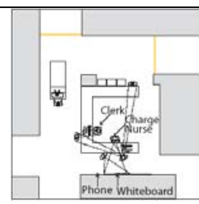
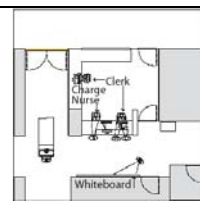
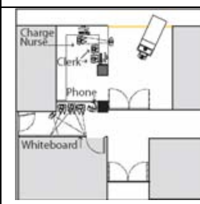
Good and bad coordination events. Next, I made sketches of the relevant aspects of the physical environment for coordination events, to situate these coordination events in the sites. For each good or bad coordination event, I hypothesized what aspects of the physical environment may have helped or hindered coordination activity. Below are some examples of good and bad coordination events I observed.

Bad coordination event at XL. Below is an example of how having the schedule whiteboard access area separate from the control desk complicates coordination.

In XL, Dr.Z, the charge anesthesiologist, was handing over the charge anesthesiologist duties to Dr. M; Dr. Z gestured at the whiteboard to explain what was happening in the surgical suite. He indicated the open operating rooms and then commented on the scheduled cases, the location of each provider, which providers needed a break, and who was available to give breaks. Dr. Z then left the surgical suite whiteboard and walked to the front desk around the corner. He returned a few minutes later and told Dr. M there were two add-on cases, but only one of them was likely to be done today. Dr. M said he would go figure out which one was the real case. Shortly after Dr. Z left, Dr. M walked to the control desk with the two patient strips to clarify the standing of the two add-on cases.

The exchanges and multiple trips of Dr. Z and Dr. M demonstrate how the location of the whiteboard away from the front desk, and hence the lack of overlap between the information access areas, interfered with smooth coordination and information exchange.

Table 4-1. Summary of integration between physical environment and information artifacts.

	Small Surgical Suite	**Medium Surgical Suite**	**Large Surgical Suite**	**XL Surgical Suite**
Thumbnail sketch of floor plan				
Staff only location	yes	yes	no	yes
Is the whiteboard in the main hallway?	yes	yes	no	no
Is the whiteboard readable from the control desk?	yes	yes	no	no
Are there places to sit out of the way?	yes	no	no	yes
Can bystanders be monitored around the control desk?	Total area	Total area	Partial area	Partial area
Are the whiteboard information access areas out of the way of indoor traffic?	yes	yes	no	yes

Good coordination event at Medium. Outside of the operating room, workers wear a white lab coat to cover their surgical scrubs. People wearing a lab coat remove it before entering into a sterile area to avoid spreading infections. In Medium, the passageway between the whiteboard and control desk leading to the coat rack is a forced stop for those wearing a lab coat before entering into the sterile corridor. As such, the connection between main hallway, whiteboard area, and coat rack ensures that surgeons and anesthesiologists have increased odds of encountering each other in front of the whiteboard.

> *Dr. W the charge anesthesiologist is looking at the whiteboard, as Dr. K, a surgeon, walks up to the control desk and is headed to the coat rack where he places his lab coat. Dr. W says hello to Dr. K and explains that there has been a change in anesthesia staffing because a difficult liver case came in and that he will be the anesthesiologist for his surgeries today. Dr. W and Dr. S move over to the whiteboard and discuss Dr. W's surgery cases for the day. They agree on the type of anesthesia for each surgery and then walk together to the patient holding area.*

The example above suggests that creating natural interaction opportunities by careful placement of forced stops can help coordination.

Bad coordination event at Large. The physical environment can affect synchronizing the information on the whiteboard. The distance between the people updating the whiteboard requires more effort to update than paper artifacts within reach.

> *One clerk explained that the clerk's job is to answer the phone, answer questions at the desk, put patients into the computer schedule system, call for the in-patients, manage the transport teams, and keep the whiteboard updated. The highest priority is to know what is happening to answer questions accurately on the phone and at the desk. Updating the whiteboard is not the first priority. If the phone is ringing, I cannot be updating the whiteboard and answering the phone at the same time. I do my best but I cannot be in two places at the same time.*

The privileging of the personal printout comes at the expense of the public display, which receives less frequent updates. An out of date whiteboard affects others. For example, if the whiteboard is not updated a surgeon and surgical equipment may go to the wrong room.

Good coordination event in Small. The charge nurse is busy calling for in-patients in the units. The phone has a very long cord so the charge nurse can walk back and forth between the phone and the whiteboard easily. While the charge nurse is making the calls an anesthesiologist approaches. They begin to discuss a difficult case listed on the whiteboard.

> *The charge nurse discusses with the charge anesthesiologist changing the order of the cases. The charge anesthesiologist asks about the status of the first patient for one room. Both refer to the cases posted on the whiteboard. They agree the order of two*

cases can be switched on the whiteboard because the first case is not ready to go. The anesthesiologist calls the surgeon on the phone to make sure that the surgeon of the second case is available. Once the anesthesiologist gets off the phone and says that the surgeon is available, the charge nurse updates the order of the cases on the whiteboard.

The charge nurse uses the whiteboard as a working document, constantly updating it as changes are decided. Therefore, the whiteboard is constantly up-to-date. In Large instead, the Clerk usually updates the whiteboard after several changes to the schedule have already occurred. As such, the whiteboard is up-to-date only after an update, but not in-between update sessions.

For each good or bad coordination event, I sketched out positive and negative aspects of the physical environment at play. At first, I used post-it notes to capture the ideas on a wall-sized display (Figure 4-2). Affinity diagramming allowed me to group the good and bad coordination into two physical environment themes: people congregating and information available.

4.2.3 Fifteen Surgical Suite Design Principles

From the work described in the preceding section, I identified fifteen basic principles extracted from the field studies to describe a configuration of the physical environment that would lead to optimal surgical suite coordination. These design principles are of two kinds: those that affect how people congregate and those that affect information available. How people congregate has three physical environment components: movement, pause locations, and barriers to congregating. The information available has three components: information display surfaces, information access areas, and barriers to information. Below, I describe each of the fifteen principles.

The movement of workers through a space relates to how connected it is to other destinations. Placing the whiteboard and control desk in Medium in a highly connected space was associated with better coordination events. Therefore:

Principle 1: Locate control desk and schedule board in a highly connected area.

Allowing workers to monitor of bystanders in pause locations encouraged spontaneous interaction among those present. I interpreted the visibility between whiteboard and control desk in Medium to be positive for coordination because people at the whiteboard and the control desk could monitor each other reciprocally. Therefore:

Principle 2: Provide pause locations that allow monitoring of bystanders.

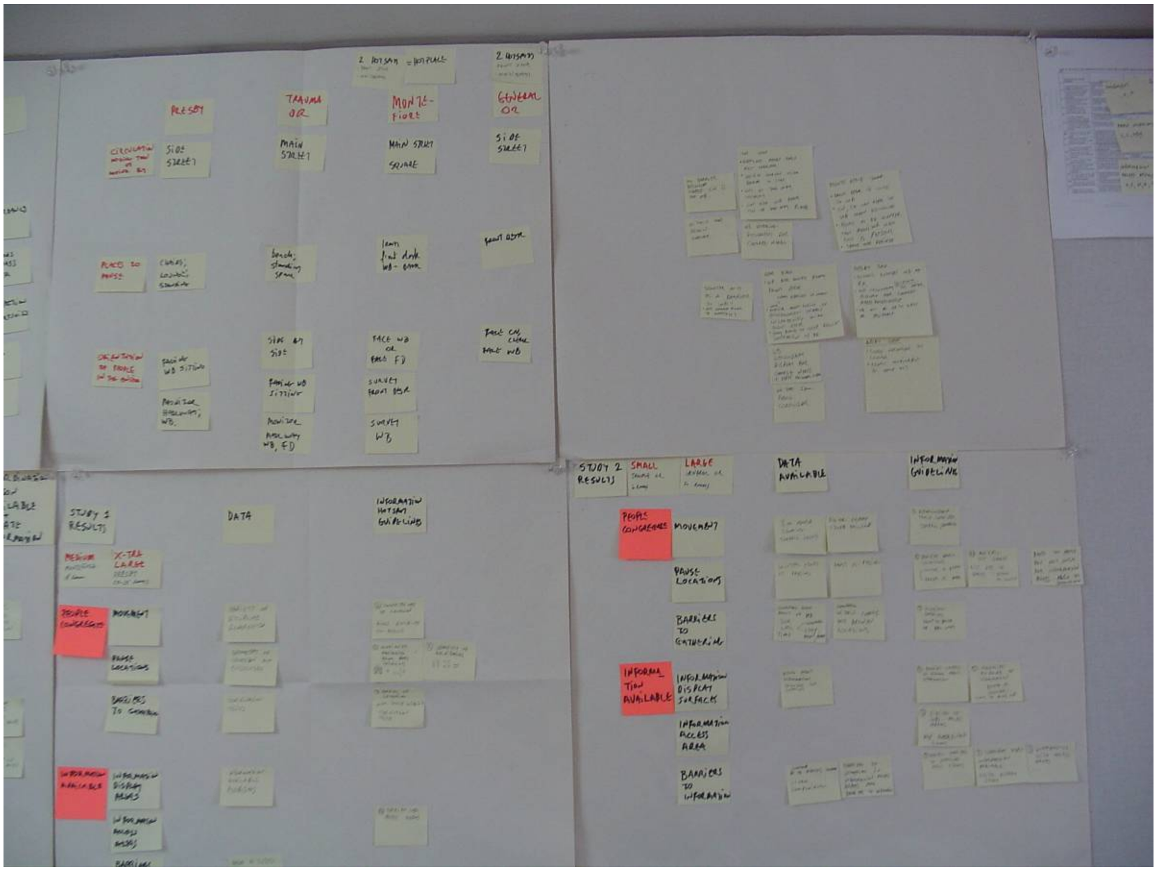


Figure 4-2. Mapping of design ideas to data and anecdotes collected in the field.

In Medium, increased inter-group visibility around the whiteboard and control desk was associated with increased interaction between groups and better coordination events. In XL, the lack of visibility between whiteboard and control desk was associated with less interaction between groups around the whiteboard and worse coordination events. Therefore:

Principle 3: Increase intergroup visibility around shared information artifacts.

In Medium, staffs could access the U-shaped control desk, on three sides. When at the control desk staffs could see everyone else present. Therefore:

Principle 4: Arrange furniture and furnishings to maximize information access areas.

In Medium, the overlap in information access areas for the whiteboard and control desk allowed workers to access information from both sources from the same spot. Easy access to information from the whiteboard and control desk was associated with better coordination events. Therefore:

Principle 5: Provide overlapping information access areas for information artifacts used together.

Those headed to or leaving the sterile corridor use the hallway leading to the sterile corridor. In Small and Medium, locating the control desk and schedule whiteboard inside the hallway leading to the sterile corridor was associated with increases interaction opportunities. Therefore:

Principle 6: Locate schedule board and control desk in a space leading to the sterile corridor.

In Small people congregated and for longer periods in the portion of the hallway furthest from the whiteboard where traffic was less likely to interrupt them. To process and discuss the information displayed on the whiteboard with those co-present some time is necessary. Therefore:

Principle 7: Put workers in pause locations out of the way of traffic.

The multiple uses in the space around the whiteboard bench in Small were associated with people congregating for longer periods, and positive coordination events. Therefore:

Principle 8: Encourage compatible multiple uses of spaces around information displays.

In both Small and Large Surgical Suites, interference from foot traffic reduced the duration workers paused. However, congregating around the whiteboard and control desk was associated with better coordination events. Therefore:

Principle 9: Size corridors to keep pause locations clear of traffic.

Patient privacy legislation limits the amount of information displayed in unprotected areas where non-staff can see it. In Large, limited information on the whiteboard complicated coordination procedures. Therefore:

Principle 10: Locate control desk and schedule whiteboard where patient privacy legislation allow displaying information.

Figure 4-3. Summary of principles according to categories derived from affinity diagramming.

In Small, the use of all vertical surfaces to display information both on the whiteboard and around it demonstrated the difference between “on-display information” freely available to those co-present, and “on-demand information” available upon request. The presence of both types of information was associated with better coordination events. Therefore:

Principle 11: Provide enough surfaces to display public information.

In Small, the location of the bench with respect to the whiteboard maximized exposure to information. Workers sitting on the bench faced the whiteboard and thus had more opportunities to see and discuss what was happening in the surgical suite. Therefore:

Principle 12: Orient furniture to maximize display exposure.

In Small, the space around the whiteboard was such that groups of 10 surgeons and surgical residents discussed the schedule on the whiteboard. I interpret allowing large groups to coordinate around the same display to be a positive for group coordination. Therefore:

Principle 13: Size information access areas so decision makers can congregate.

In Large Surgical Suite the counter, the door, and the telephone acted as barriers that increased the effort necessary to update the whiteboard causing the whiteboard to be out-of-date. Coordination was complicated as a result. Therefore:

Principle 14: Reduce effort necessary to update information displays.

The information access area for the whiteboard in Large Surgical Suite coincided with the center of the hallway. Traffic intermittently occupied the hallway. These two activities are in conflict. Therefore:

Principle 15: Separate information access areas from conflicting activities.

In Table 4-2, the first column lists the 15 principles, the middle column indicates whether it is associated with people congregating or information available, and the rightmost column indicates how it is associated with the physical environment.

Comparing the surgical suites. In Table 4-3, I use these 15 principles to evaluate the Pennsylvania surgical suites XL and Medium and the Maryland surgical suites Large and Small. I rated compliance with each principle with a one and non-compliance with a zero. Medium and Small have greater compliance with the principles. The XL and Large Surgical Suite have lower compliance scores. In this section, I describe the problems with XL and Large. In the next section, I describe design strategies to improve XL and Large.

The main problems for XL are reduced interaction opportunities around the whiteboard, reduced inter-group congregating around the whiteboard, and lack of integration between the information at the whiteboard and control desk. XL met four of the fifteen principles (7,11,12, and 14); five principles related to people congregating were not met (1,2,3,8, and 9); six principles about the availability of information were not met (4,8,9,10, 13, and 15).

The two main problems for Large are reduced interaction and congregating opportunities around the whiteboard and limited and out-of-date information on the whiteboard. Large met three principles (1, 11, and 13); five principles regarding people congregating are not met (2,6,7,8, and 9); seven principles regarding information available are not met (4,5,10,11,12,14, and 15).

Table 4-2. Design principles derived from the field studies.

	Design Principle	Related to	The physical environment is associated with
1	Locate control desk and whiteboard in a highly connected area.	People congregate	Movement
2	Provide pause locations that allow monitoring of bystanders.	People congregate	Pause locations
3	Increase intergroup visibility around shared information artifacts.	People congregate	Pause locations
4	Arrange furniture and furnishings to maximize information access areas.	Information is available	Information access areas
5	Provide overlapping information access areas for information artifacts used together.	Information is available	Information access areas
6	Locate schedule whiteboard and control desk in a space leading to the sterile corridor.	People congregate	Movement
7	Put workers in pause locations out of the way of traffic.	People congregate	Pause locations
8	Encourage compatible multiple uses of spaces around information displays.	People congregate	Pause locations
9	Size corridors to keep pause locations clear of traffic.	People congregate	Pause locations
10	Locate control desk and schedule whiteboard where patient privacy legislation allow displaying information.	Information is available	Movement
11	Provide enough surfaces to display public information.	Information is available	Information surfaces
12	Orient furniture to maximize display exposure.	Information is available	Information visible
13	Size information access areas so decision makers can congregate.	Information is available	Information access areas
14	Reduce effort necessary to update information displays.	Information is available	Barriers to information
15	Separate information access areas from conflicting activities.	Information is available	Information access areas

4.3 Design Strategies

There are many possible solutions to the problems identified with adherence to the design principles above. In this section, I describe a tiered design strategy according to implementation effort. In minimum effort interventions, the physical environment remains unchanged and existing information artifacts can move. A medium effort intervention involves adding technology. Greater effort interventions involve changing the presence or location of walls, doors, etc., changing the use of spaces, and changing information artifacts. I use concept sketches to quickly communicate the design ideas and describe technology solutions in terms of the affordances provided. Detailed architectural solutions go beyond the scope of this dissertation given the complexity of the surgical suite setting (i.e., air flow and zones, electrical systems, state legislation, etc).

Table 4-3. Comparing the four locations studied side by side with the 15 principles. (0=no; 1 = yes)

		Pennsylvania Study		**Maryland Study**	
	Information Hotspot Principle	**XL**	**Medium**	**Large**	**Small**
1	Locate control desk and whiteboard in a highly connected area.	0	1	1	1
2	Provide pause locations that allow monitoring of bystanders.	0	1	0	1
3	Increase intergroup visibility around shared information artifacts.	0	1	1	1
4	Arrange furniture and furnishings to maximize information access areas.	0	1	0	1
5	Provide overlapping information access areas for information artifacts used together.	0	1	0	1
6	Locate schedule board and control desk in a space leading to the sterile corridor.	0	1	0	1
7	Put workers in pause locations out of the way of traffic.	1	1	0	1
8	Encourage compatible multiple uses around information displays.	0	1	0	1
9	Size corridors to keep pause locations clear of traffic.	0	1	0	1
10	Locate control desk and schedule whiteboard where patient privacy legislation allow displaying information.	0	1	0	1
11	Provide enough surfaces to display public information.	1	0	0	1
12	Orient furniture to maximize display exposure.	1	0	0	1
13	Size information access areas so decision makers can congregate.	0	1	1	1
14	Reduce effort necessary to update information displays.	1	0	0	1
15	Separate information access areas from conflicting activities.	0	1	0	1
	total	**4**	**13**	**3**	**15**

The purpose of the concept sketches is to explore the design space. I develop multiple solutions to illustrate the design strategies for XL Surgical Suite and Large Surgical Suite and evaluate each solution using the principles. I propose solutions that range in implementation effort. I use the design principles to assess a wide range of solutions.

XL surgical suite concept sketches. XL Surgical Suite suffered most from the physical separation between the whiteboard and the control desk. First, the whiteboard and the control desk were far apart. Second, the hallway with the surgical suite whiteboard is not visible from the control desk. Third, the narrow hallway limited the number of people who can see the whiteboard at the same time without getting in each other's way. In the following four sections, I provide concept sketches. In Table 4-4 and Table 4-5, I compare the four solutions with the design guidelines: move the whiteboard, add video and audio links, open a window onto the schedule board, and move the doors and make a central control desk.

Sketch 1: Move the whiteboard. The first concept sketch for XL Surgical Suite entails moving the schedule whiteboard to the space in front of the control desk (Figure 4-4). Placing the schedule whiteboard here would allow the nursing team and the anesthesia team more interaction opportunities. Each time a member of the anesthesia team is checking or updating the schedule whiteboard is an interaction opportunity with the nursing team behind the control desk.

Sketch 2: Add video and audio links. The second concept sketch entails adding technology to afford reciprocal monitoring between the schedule whiteboard and the control desk (Figure 4-4). A two-way intercom system affords communication without using the phone, thus letting bystanders in the area overhear the communication. Addressing privacy concerns is critical for this kind of media solution (e.g., Nardi et al., 1993). The phone line complements the intercom system and affords communication with only one person at a time in each location.

Sketch 3: Open a window onto the schedule whiteboard. The third concept sketch involves opening a window between the schedule whiteboard area and the control desk (Figure 4-5). The visual connection between the two areas would afford a shared view onto the schedule whiteboard. The nursing team could thus monitor the whiteboard as a feedback loop regarding recent changes to the surgical suite schedule not yet displayed on the whiteboard. A two-way intercom system would link the two areas thus affording communication when necessary, but also providing acoustic privacy. The decision to leave a glass division between the two locations is to avoid having to change the airflow system between the two areas.

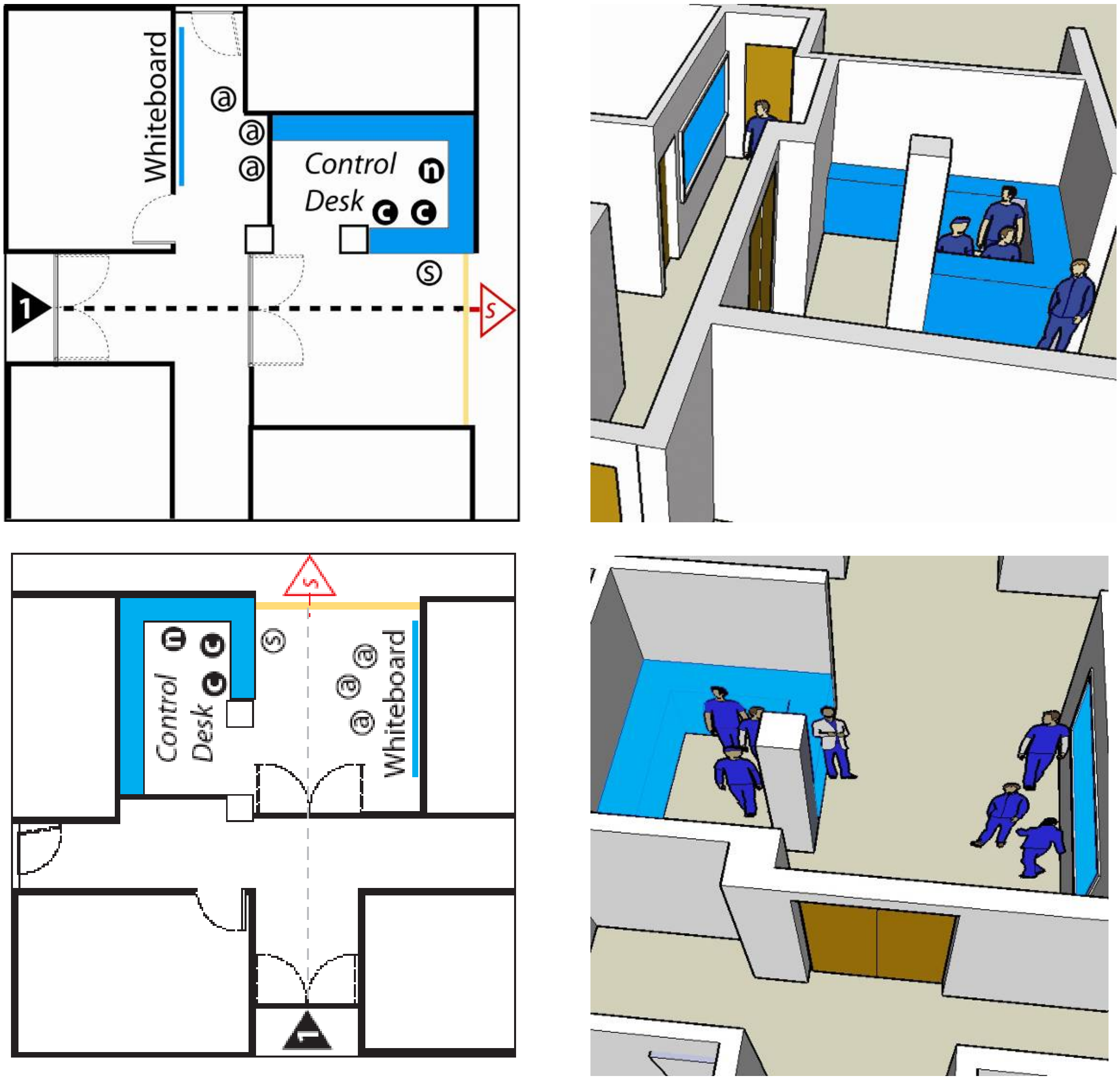


Figure 4-4. (Top row) Current state during field study. (Bottom row) Concept sketch, move the whiteboard in front of the control desk. Note the floor-plan is rotated 90 degrees counter-clockwise to show the whiteboard in front of the control desk.

Sketch 4: Move the doors and make a central control desk. The fourth concept sketch involves a radical redesign of the control desk, moving the automatic doors (Figure 4-5). The airflow system would need to be adapted in this solution. The schedule whiteboard would be visible from the control desk. The nursing team and the anesthesia team would be able to easily monitor each other. Both teams could refer to the same whiteboard while discussing schedule options.

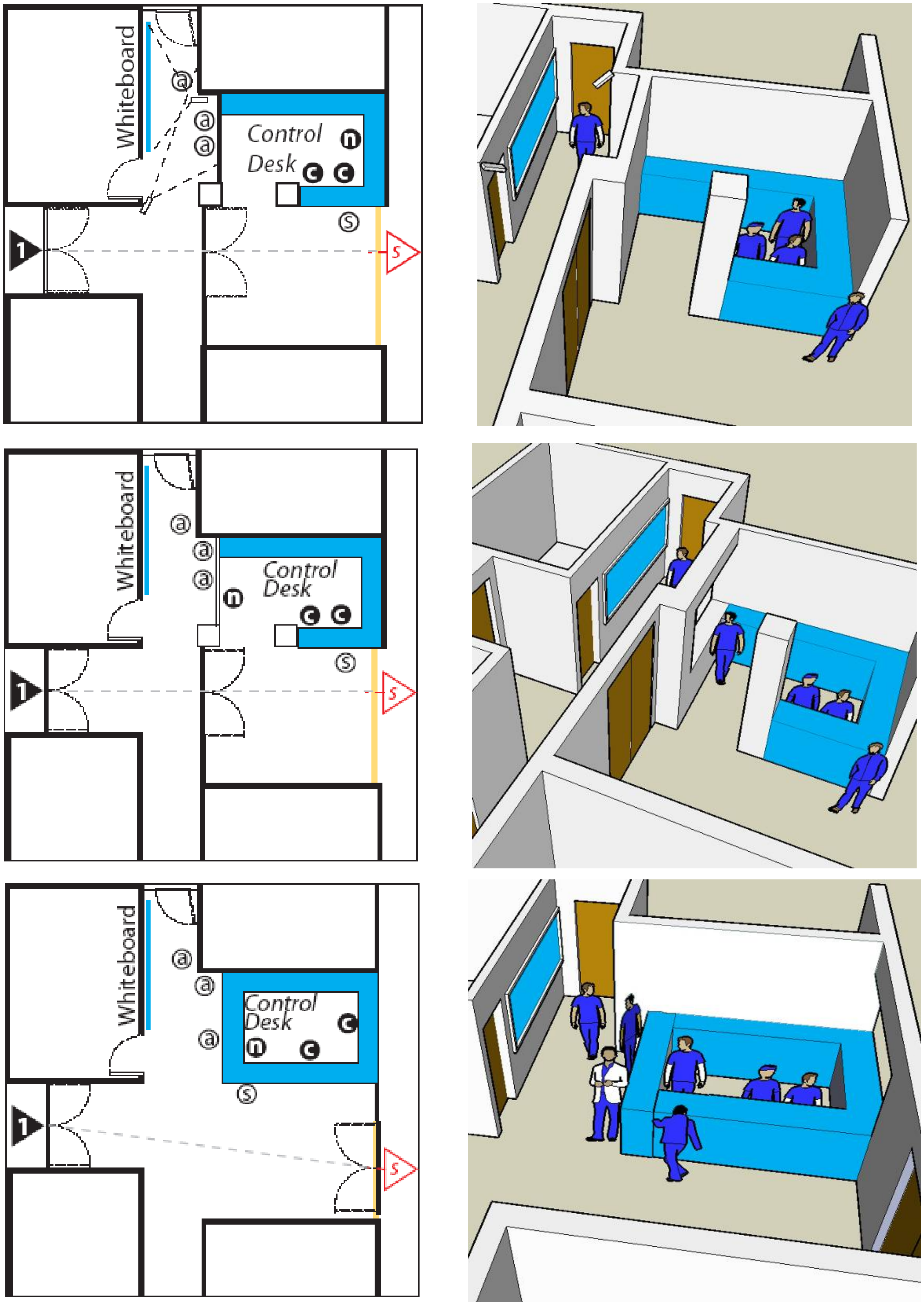


Figure 4-5. (Top) Video and audio links connect the whiteboard area and the control desk. (Middle) A glass window and audio link connect the whiteboard area and the control desk. (Bottom) New control desk adjacent to the whiteboard and lounge.

This solution encourages congregating around the control desk. The control desk counter is open on two sides thus allowing surgeons, anesthesia, and control desk workers to meet near the whiteboard. The new automatic door is away from the control desk to create an area where people can pause around the control desk. The resulting diagonal path to the sterile corridor reduces potential interference from traffic with people pausing around the control desk.

Table 4-4. Comparing the status of XL Surgical Suite when the field study was conducted the four concept sketches proposed, (0=no; 1 = yes).

	Information Hotspot Principles	**XL**	**1 Move WB**	**2 Closed circuit**	**3 Glass window**	**4 Move doors**
1	Locate control desk and whiteboard in a highly connected area.	0	1	0	0	1
2	Provide pause locations that allow monitoring bystanders.	0	0	1	1	1
3	Increase intergroup visibility around shared information artifacts.	0	1	1	1	1
4	Arrange furniture and furnishings to maximize information access areas.	0	0	1	1	1
5	Provide overlapping information access areas for information artifacts used together.	0	0	0	0	1
6	Locate schedule board and control desk in a space leading to the sterile corridor.	0	1	0	0	1
7	Put workers in pause locations out of the way of traffic.	1	1	1	1	1
8	Encourage compatible multiple uses of spaces around information displays.	0	0	0	0	1
9	Size corridors to keep pause locations clear of traffic.	0	1	1	1	1
10	Locate control desk and schedule whiteboard where patient privacy legislation allow displaying information.	0	1	0	0	1
11	Provide enough surfaces to display public information.	1	1	1	1	1
12	Orient furniture to maximize display exposure.	1	0	1	1	1
13	Size information access areas so decision makers can congregate.	0	0	0	0	1
14	Reduce effort necessary to update information displays.	1	0	1	1	1
15	Separate information access areas from conflicting activities.	0	1	1	1	1
	Total	4	8	9	9	15

Concept Sketches for Large Surgical Suite. Large surgical suite suffered most from the characteristics of the physical environment around the control desk and the whiteboard. Four physical factors at Large Surgical Suite hindered coordination around the control desk and the whiteboard: First, the whiteboard is in an unrestricted hallway, and thus information it displays is limited. Second, the surgical suite whiteboard is across the hallway from the whiteboard updaters. The distance from the whiteboard and a constantly ringing phone at the control desk reduce opportunities to update it. Third, the whiteboard is difficult to read from the control desk, and thus, the updaters receive little benefit from updating the whiteboard. Fourth, the information access areas to the whiteboard and the control desk do not overlap. Next, I provide concept sketches for Large Surgical Suite: change the whiteboard, project the schedule from the control desk, replace the whiteboard with an electronic display, and modify the control desk. I compare the current state of Large Surgical Suite with the four alternative concept design solutions.

Sketch 1: Change the layout of the whiteboard. The first concept sketch for Large Surgical Suite involves first modifying the traffic patterns so that that the family members of patients do not pass in front of the schedule whiteboard and then addressing two whiteboard problems.

The whiteboard and control desk need to become a staff-only area so the whiteboard can display all necessary information. A way finding solution is necessary to so that non-authorized people can find the route to the post-anesthesia care unit. Some way finding suggestions are better signage, drawing lines to follow on the floor, placing orientation maps in the building, and giving people maps to carry.

The first problem is that the whiteboard is not visible from the control desk. Currently only 1/3 of the whiteboard's surface is used to display information regarding surgical procedures. As such, the control desk workers write the surgical procedure information small so that it will fit in the allotted space. The small writing is not easily readable from the control desk. A reorganization of the surgical suite whiteboard would allow the writing to be larger and legible from a greater distance.

The second problem with the schedule whiteboard regards the distance between its position and where the assigned updaters sit to work. Those working behind the control desk have the burden of answering the phone and fielding questions at the front desk. Consequently, they make changes to the surgical suite schedule on their paper artifacts and then update the whiteboard when there is a calm moment.

Restaurants have a similar problem with the official menu and the daily specials. Restaurants have resolved the menu problem by placing the daily specials on a blackboard, having the servers recite the specials menu, or handing out paper printouts with the menu. Likewise, clerks could write the last minute schedule changes to a special whiteboard at the control desk. Both the large whiteboard and the small whiteboard would have to be time-stamped so staff would know what information is probably accurate. The whiteboard viewers would have to integrate the information from both the small and the large whiteboard. The last minute changes small whiteboard solution is inexpensive and easy to implement but is not ideal because it requires people to integrate information from two sources (Wickens & Carswell, 1995).

Sketch 2: Project the schedule from the control desk. The first technology solution uses an overhead projector (or a camera and projector combination) to replace the whiteboard. The control desk staff could write the schedule information onto a transparency (or on a paper artifact) projected onto the wall across the hall. The control desk workers could update the changes to the schedule without leaving their chair.

Sketch 3: Replace whiteboard with an electronic display. Another technology solution involves replacing the schedule whiteboard with a computer system display. The computer system would have to be easy to update, so that the updaters would update the system continuously as changes occur. Furthermore, the large display computer system would have to be legible from the control desk so the updaters refer to the display while answering questions.

Sketch 4: Modify the control desk. In this concept sketch, I propose major changes. I remove a wall to make the control desk accessible on two sides; I reduce the footprint of the control desk area widening portions of the two hallways around the control desk and whiteboard to ten feet. I assign eight feet of the corridor to local traffic and a two-foot wide traffic-free area to pausing around the control desk. The smaller control desk allows workers to congregate on two sides and monitor bystanders. The control desk would open directly onto the main path leading to the sterile corridor. The whiteboard would have to be altered to allow the information it contains to be legible from the inside of the control desk. Thus, control desk workers can reference the whiteboard to answer questions at the control desk (Figure 4-6).

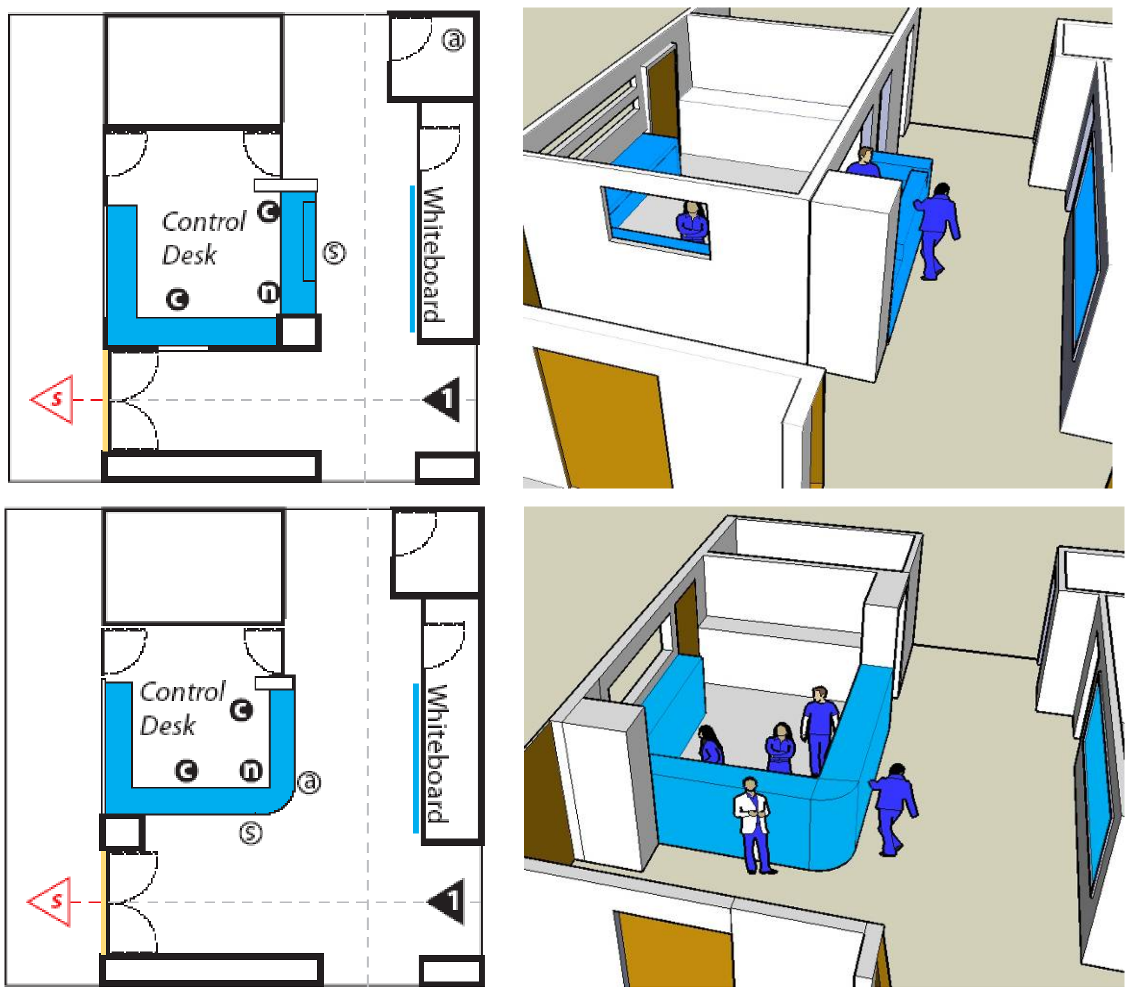


Figure 4-6. (Top) Large Surgical Suite as it was during the field study. (Bottom) Concept sketch with open control desk and more space to accommodate people around both sides of the control desk undisturbed by indoor traffic.

Table 4-5 summarizes the scores for the Large Surgical Suite design alternatives according to the 15 design principles. Large upon first evaluation complied with three of the fifteen principles. The lower effort design alternatives raised the score to seven and the greatest effort solution boosted the score to thirteen. The design alternatives all had four principles in common: Provide overlapping information access areas for information artifacts used together; locate control desk and schedule whiteboard where patient privacy legislation allows information posted; reduce effort necessary to update information displays; and separate information access areas from conflicting activities. The high implementation effort alternative added compliance to six principles. Allow monitoring of bystanders in pause locations; arrange furniture to maximize information access areas; locate whiteboard and control desk in a space leading to the sterile corridor; put workers in pause locations out of the way of traffic; size corridors to keep pause locations clear of traffic; and orient furniture to maximize display exposure.

Discussion. The current state of Large Surgical Suite and the design alternatives described in this section range from compliance with three, seven, and thirteen principles. I assessed each guideline individually with a zero or a one. The total score assumes that all the principles are of equal importance. However, it is unclear if all principles actually have equal weight in creating successful information hotspots. More work is necessary to determine the correct weighting for each design principle.

Comparing the highest scoring concept sketches. The highest scoring solutions in both surgical suites require the greatest implementation effort. XL Surgical Suite concept sketch 4 meets all fifteen principles. Large Surgical Suite concept sketch 4 meets thirteen principles. In XL Surgical Suite, the concept sketch suggests opening of the wall between the whiteboard and the control desk. Removing the wall between the whiteboard and control desk creates a visual link between control desk workers and anesthesiologists. The whiteboard is a focal point for the anesthesia team because it is located next to the anesthesia lounge. In the concept sketch, stools are present at the control desk counter near the whiteboard to allow anesthesia workers to sit at the counter and look at the whiteboard (Table 4-6).

The lower score in Large results from two principles: increase intergroup visibility around shared information artifacts and encourage compatible multiple uses of spaces around information displays. Both principles relate to pause activity for anesthesiologists and nurses around the whiteboard and control desk. I noted in the Maryland field study, that it is not enough to walk by the control desk or whiteboard, workers need to pause enough to provide or receive information. Multiple activities that encourage workers to stop around the control desk and whiteboard can encourage such exchanges (Table 4-6).

Table 4-5. Comparing the status of Large Surgical Suite status quo and four concept sketches. (0=no; 1 = yes)

	Information Hotspot Principle	**Large SurgicalSuite**	**1 Fix WB**	**2 Analog Project**	**3 Digital Schedule**	**4 Open Desk**
1	Locate control desk and whiteboard in a highly connected area.	1	1	1	1	1
2	Provide pause locations that allow monitoring of bystanders.	0	0	0	0	1
3	Increase intergroup visibility around shared information artifacts.	0	0	0	0	0
4	Arrange furniture and furnishings to maximize information access areas.	0	0	0	0	1
5	Provide overlapping information access areas for information artifacts used together.	0	1	1	1	1
6	Locate whiteboard and control desk in a space leading to the sterile corridor.	0	0	0	0	1
7	Put workers in pause locations away from traffic.	0	0	0	0	1
8	Encourage compatible multiple uses of spaces around information displays.	0	0	0	0	0
9	Size corridors to keep pause locations clear of traffic.	0	0	0	0	1
10	Locate control desk and schedule whiteboard where patient privacy legislation allows information posted.	0	1	1	1	1
11	Provide enough surfaces to display public information.	1	1	1	1	1
12	Orient furniture to maximize display exposure.	0	0	0	0	0
13	Size information access areas so decision makers can congregate.	1	1	1	1	1
14	Reduce effort necessary to update information displays.	0	1	1	1	1
15	Separate information access areas from conflicting activities.	0	1	1	1	1
	Total	3	7	7	7	13

4.4 Consolidating the Design Principles into Guidelines.

The design guidelines described in this chapter are in progress and evolving. Above, I started with a list of fifteen design principles. I will use the list of design principles to develop evaluation checklists and selection criteria. The longer list of principles has fewer ideas per item and thus is easier to use as a checklist. However, for the layperson, the relationships between the individual principles may be difficult to grasp. In this section, to facilitate comprehension, I group related principles together into a reduced number of design guidelines. Limiting the number of design guidelines should make them easier to remember as well (Miller, 1956).

Table 4-6. Compares the current state and the best concept design alternative for XL Surgical Suite and Large Surgical Suite. (0=no; 1 = yes)

		Study 1 Location		**Study 2 Location**	
	Information Hotspot Design Principle	**XL OR Suite**	**4 Move doors**	**Large OR Suite**	**4 Open Desk**
1	Locate control desk and schedule board in a highly connected area.	0	1	1	1
2	Provide pause locations that allow monitoring of bystanders.	0	1	0	1
3	Increase intergroup visibility around shared information artifacts.	0	1	0	0
4	Arrange furniture and furnishings to maximize information access areas.	0	1	0	1
5	Provide overlapping information access areas for information artifacts used together.	0	1	0	1
6	Locate surgical suite schedule board and control desk in a space leading to the sterile corridor.	0	1	0	1
7	Put workers in pause locations out of the way of traffic.	1	1	0	1
8	Encourage compatible multiple uses of spaces around information displays.	0	1	0	0
9	Size corridors to keep pause locations clear of traffic.	0	1	0	1
10	Locate control desk and schedule board where patient privacy legislation allow displaying information.	0	1	0	1
11	Provide enough surfaces to display public information.	1	1	1	1
12	Orient furniture to maximize display exposure.	1	1	0	1
13	Size information access areas so decision makers can congregate.	0	1	1	1
14	Reduce effort necessary to update information displays.	1	1	0	1
15	Separate information access areas from conflicting activities.	0	1	0	1
	Total	**4**	**15**	**3**	**13**

Table 4-7 maps the short list of guidelines to the longer list of principles. In the next section, I explain each of the eight guidelines with diagrams. To make the eight guidelines easier to remember yet, I grouped them into two sections: those regarding the architecture and those regarding information available. Five guidelines regard architecture (i.e., space adjacency, connectivity, and access areas). Three guidelines regard information (i.e., communication practices, schedule board characteristics).

Table 4-7. The short guideline list and the long principle list side by side.

	Information Hotspot Design Guidelines		**Information Hotspot Design Principles**
1	Place the schedule board[8] and control desk so that they are mutually visible and their access areas overlap, and so that staff from the control desk can easily update the schedule board.	3	Increase intergroup visibility around shared information artifacts.
		5	Provide overlapping information access areas for information artifacts used together.
		14	Reduce effort necessary to update information displays.
2	Locate the schedule board and control desk in a highly connected area leading to the sterile corridor and separate from conflicting activities.	1	Locate control desk and schedule board in a highly connected area.
		6	Locate schedule board and control desk in a space leading to the sterile corridor.
		15	Separate information access areas from conflicting activities.
3	Provide pause locations for people to access the schedule board and control desk that are out of the way of traffic, allow monitoring of bystanders, and make corridors wide enough to allow traffic to pass.	2	Provide pause locations that allow monitoring of bystanders.
		7	Put workers in pause locations out of the way of traffic.
		9	Size corridors to keep pause locations clear of traffic.
4	Arrange furniture and furnishings around the schedule board and control desk to make the size of the information access areas large so that decision makers can congregate.	13	Size information access areas so decision makers can congregate.
5	Encourage compatible multiple uses of spaces around information displays.	8	Encourage compatible multiple uses of spaces around information displays.
6	Locate the schedule board where patient privacy legislation allows displaying information.	10	Locate control desk and schedule board where patient privacy legislation allow displaying information.
7	Orient furniture to maximize information display exposure.	4	Arrange furniture and furnishings to maximize information access areas.
		12	Orient furniture to maximize display exposure.
8	Provide enough surfaces to display information.	11	Provide enough surfaces to display public information.

[8] I use the term schedule board to refer to both manual whiteboards and electronic schedule boards.

The eight guidelines. The architecture setting is associated with coordination near the surgical suite schedule board and control desk. The information hotspots concept in the surgical suite describes (a) how the physical environment is associated with where workers congregate. (b) What information resources are available. (c) What information resources are accessible. I describe surgical suite information hotspots around schedule boards and control desks design guidelines in terms of two key dimensions the architecture of the built environment and the information available.

4.4.1 Architecture

The architecture of the built environment in surgical suites operates at two levels, the building level configuration (i.e., space adjacency and connectivity) and the local level configuration, of interest here are access areas around schedule boards and control desks.

Space adjacency. Space adjacency determines what spaces are side by side and so forth. Factors associated with space adjacency include visibility, distance, and larger circulation patterns around the schedule board and control desk. Space adjacency is associated with congregating behavior around the schedule board and control desk. People visited the schedule board more often when it was located in sight of the control desk, and this led to more interactions among staff members at the schedule board, increasing opportunities to coordinate. Therefore:

> *Guideline 1: Place the schedule board and control desk so that they are mutually visible and their access areas overlap, and so that staff from the control desk can easily update the schedule board.*

In Figure 4-7, the blue line represents the schedule board; the elliptical dotted line traces the access area from which the schedule board is legible. The blue square represents the control desk. The shaded blue circle represents the area from which conversations at the control desk are audible. The schedule board and control desk are both accessible in the overlapped areas.

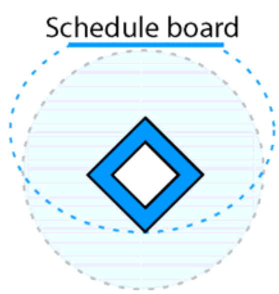


Figure 4-7. Schedule board and control desk are mutually visible and close enough to be mutually accessible. The donut represents the control desk and the dotted lines are where the schedule board and control desk are accessible.

Connectivity. Connectivity refers to how connected one space is to the other. Generally, spaces that are more central have greater connectivity to other spaces. Task related connectivity refers to how connected are spaces that must be visited to conduct a particular task. In the field studies, areas that scored high on task-related connectivity had more workers pause around the schedule board and control desk. Inversely, areas with lower task-related connectivity had fewer workers pause around the schedule board and control desk. Therefore:

> *Guideline 2: Locate the schedule board and control desk in a highly connected area leading to the sterile corridor and separate from conflicting activities.*

In Figure 4-8 the black triangle indicates an entry into the surgical suite area; the black dotted line indicates the main path to the sterile corridor; the s in the red triangle represents the sterile corridor; the grey dotted lines denote the secondary hallways. As the figure illustrates the control desk is near the schedule board, in a central location where many paths converge, and the entry to the sterile corridor is visible.

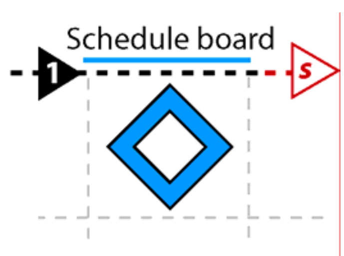


Figure 4-8. The main corridor crosses the schedule board and control desk (represented with a black dotted line) leading to the sterile corridor (s) and in a highly connected place (grey dotted lines represent other paths).

Access areas. The next guidelines deal with local areas around the schedule board and the control desk. The characteristics of the areas around the schedule board and control desk traffic can conflict with information access when people looking at the schedule board move out of the way to let traffic by. Traffic does not interfere will everyone though; traffic takes the easiest path. In the Small Surgical Suite, traffic travels around workers sitting on the bench but forces the workers standing in the hallway to move. In the Large Surgical Suite, traffic moves around workers holding on to counter but forces staff that is looking at the schedule board to move. Workers congregating can serendipitously coordinate with others congregating. In the Medium Surgical Suite, the U-shaped control desk was accessible on three sides; workers can monitor bystanders and coordinate serendipitously. Therefore:

> *Guideline 3: Provide pause locations for people to access the schedule board and control desk that are out of the way of traffic, allow monitoring of bystanders, and make corridors wide enough to allow traffic to pass.*

Figure 4-9 shows a schedule board as a solid blue line, the dotted blue line represents the area from which the schedule board is readable. The dotted line with the one in a triangle and s in a triangle represents a path from the area outside the surgical suite to the sterile corridor. The blue rectangle is the control desk. The letters in the circles outside the control desk are *a* charge anesthesiologist and *s* surgeon. Inside the control desk, *n* nurse, and *c* charge nurse.

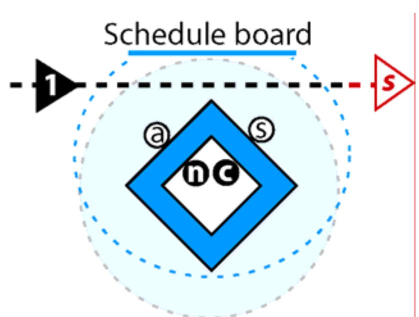


Figure 4-9. Corridors are wide enough to allow people to pause, monitor bystanders, and traffic to pass uninterrupted. The letters represent in the circles represent *a* the charge anesthesiologist, *n* the charge nurse, *c* the clerk, and *s* the surgeon.

In the Medium Surgical Suite, the U-shaped control desk and easily readable schedule board allowed workers to discuss changes to the schedule while referring to the same information on the schedule board. Therefore:

> *Guideline 4: Arrange furniture and furnishings around the schedule board and control desk to make the size of the information access areas large so that decision makers can congregate.*

In Figure 4-10, the rectangle represents the control desk; the dotted line indicates a path headed towards the sterile corridor. The position of the control desk and schedule board allows the charge anesthesiologist, surgeon, charge nurse, and clerk to congregate and view the schedule board.

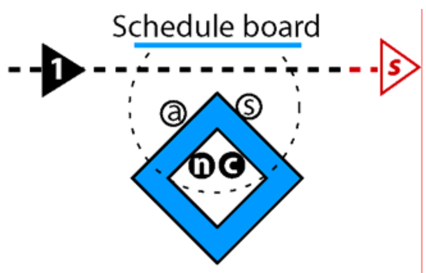


Figure 4-10. Information access areas around the schedule board and control desk allow key decision makers to congregate. The *a* represents the charge anesthesiologist, *n* the charge nurse, *c* the clerk, and *s* the surgeon. The dotted semicircle indicates an area around the schedule board where decision makers can congregate.

Serendipitous information exchange occurred in the Small Surgical Suite where the schedule board was in a staff-only location and multiple activities occurred around a bench facing the schedule board. People sat on the bench to put on surgical shoe covers, wait in between tasks, take notes, discuss the schedule, await instructions from the charge nurse, and so forth. Therefore:

> *Guideline 5: Encourage compatible multiple uses of spaces around information displays.*

In Figure 4-11, the rectangles and circles represent places where workers can sit and see the schedule board.

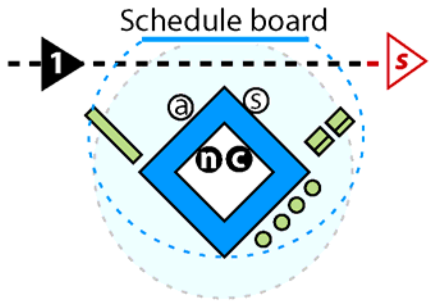


Figure 4-11. Benches, stools, or chairs (rectangles, circles) around the control desk (large square), with a view onto the schedule board encourage multiple activities. The *a* represents the charge anesthesiologist, *n* the charge nurse, *c* the clerk, and *s* the surgeon.

4.4.2 Information

The placement of information near groups is contingent on larger traffic patterns in surgical suites. Patient privacy legislation determines information displayed to staff and the public. The location of the schedule board and control desk thus determines information access. As discussed previously, on one hand less information is available where the public can see it. On the other hand, more information is available to staff in a staff only area. Therefore:

> *Guideline 6: Locate the schedule board where patient privacy legislation allows displaying information.*

In Figure 4-12, the dark rectangle keeps the public away from the schedule board and control desk. Thus, workers have access to necessary information while respecting privacy laws.

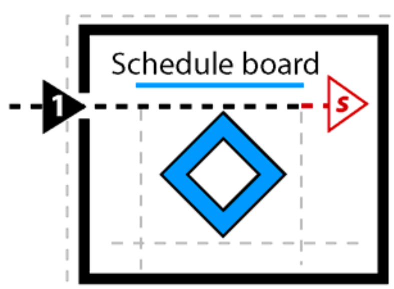


Figure 4-12. Schedule board and control desk are in a core area for authorized workers only; non-authorized persons circulate around the perimeter.

Placement and shape of furniture is associated with multiple uses, and access to information. In the Small Surgical Suite, the bench along the wall let workers sit and discuss the schedule board, whereas in Large Surgical Suite the front desk counter in front of the schedule board did not let anyone face control desk workers and the schedule board at the same time. Therefore:

Guideline 7: Orient furniture to maximize information display exposure.

In Figure 4-13, the blue square is the control desk at a 45-degree angle with the schedule board; like this people on two sides of the control desk can face the schedule board and control desk workers with ease. All present can see each other and the schedule board with ease.

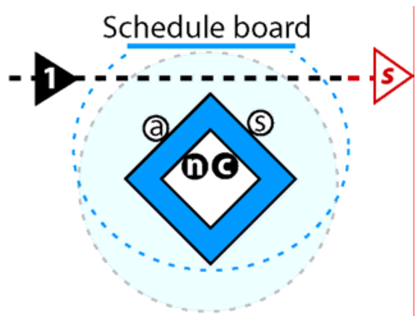


Figure 4-13. Orienting the control desk at a 45-degree angle exposes two sides to the schedule board. The *a* represents the charge anesthesiologist, *n* the charge nurse, *c* the clerk, and *s* the surgeon.

Information covered schedule boards, bulletin boards, countertops, and walls around the control desk. In Small Surgical Suite, staff could access it directly, whereas, in Large Surgical Suite, the control desk workers mediated much of it, but complained about the large volume of information requests. Therefore:

Guideline 8: Provide enough surfaces to display information.

Figure 4-14 is a three dimensional representation of a control desk, a wall with a bulletin boards and a large schedule board, and a column. The wall surface, the control desk surface, and column are potential information display surfaces.

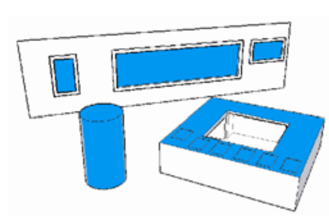


Figure 4-14. Many surfaces can host information around the schedule board and control desk (i.e., walls, columns, and furniture surfaces).

4.5 Limitations

The design principles and design guidelines presented in this chapter suffer from two main limitations: generalizability beyond the surgical suites studied, and equal weighting of the design principles.

First, the surgical suites I studied to develop the design principles and design guidelines differed along a number of workplace related dimensions (i.e., number of operating rooms, amount of surgeries they needed to coordinate, and type of surgical suites) in addition to their configuration of the physical environment. As such, I cannot be certain, based on the field studies alone, that the differences in interaction opportunities, congregating activity, and information available I observed are a function of only the architectural configuration. A better understanding of the linkages between the attributes of the architecture, information available, and coordination processes and outcomes is necessary. Also, I need to determine if factors regarding the workplace (i.e., number of operating rooms, coordination load, surgical services provided) are associated with congregating activity, update activity, and coordination outcomes. To achieve such goals I need to collect data on schedule board use across a large sample of surgical suites.

Second, to evaluate both the status quo and design alternatives, I weighed each design principle equally. This weighting scheme assumes that the design principles have the same impact on the likelihood that information hotspots formation. Intuitively, it seems more likely that some factors will contribute more to information hotspot formation than other factors.

The workplace factors (i.e., number of operating rooms, surgeries per room) for the four surgical suites that I studied to develop the design principles differed. As such, it could be that different weighting schemes are necessary for the design principles according to workplace factors.

In the next chapter, I discuss my survey of surgical suite directors nationwide.

Chapter 5: A National Survey of Space, Schedule boards, and Coordination in Hospital Surgical Suites

Scheduling surgeries in hospitals is one of the most challenging activities that surgical staff do. In some hospitals, on some days, the schedule updates affecting staff workloads, patient safety, and the financial status of the hospital occur every few minutes. In the previous chapters, I developed the concept of "information hotspot," a physical place where people meet to exchange information about the schedule, where public displays (mainly, schedule boards) offer up-to-date information about the schedule, and where coordination workers manage and maintain scheduling information. I studied information hotspots in four surgical suites in two large healthcare centers, and developed design guidelines based on positive and negative coordination events associated with the architectural features of each hotspot. The field studies were helpful in developing an in-depth understanding linkages of how architectural features, information, and coordination around the schedule in specific surgical suites. However, these case studies are insufficient to generalize about the linkages between architectural features and coordination.

To address the generalizability of my field studies, and to obtain a better understanding of how space, public displays, and collaboration are associated in different kinds of hospitals, I administered a national (U.S.) survey. I also wanted to test whether my conclusions and guidelines could be applied to electronic schedule boards. I sent a single mail survey to 1184 surgical suite directors nationwide. Of these, 135 directors responded.[9] I was able to determine that some of the architectural factors described in the design guidelines such as the visibility of a schedule board from a control desk, do matter for coordination. I controlled for workplace factors such as number of operating rooms, scheduling load, and type of surgery services provided.

[9] Low response rates may entail non-response error when respondents differ from those that did not respond (Dillman 1991). I discuss this issue in the methods section of this chapter.

This chapter proceeds as follows: I first present a model of how architectural features of surgical suites may predict information sharing and coordination outcomes. I present hypotheses drawn from this model. Next, I describe the national survey study I used to test these hypotheses, and describe my analyses and findings.

5.1 Theoretical Framework and Hypotheses

The framework includes three main sets of variables associated with scheduling surgeries—the hospital environment, information sharing, and coordination outcomes (see Figure 5-1). Within the hospital environment, I measured workplace variables including hospital size and surgeries per room. Architecture variables included measures of how visible scheduling boards were from the control desk, and measures of how frequently people sat and gathered in the area in front of the schedule board. Information variables included communication and information technologies for sharing information. I designed information sharing measures to describe how much surgical suite staff congregated around the schedule board and how often they updated the schedule. Coordination outcomes were coordination speed (how quickly surgical suite staff found out about schedule changes) and coordination stress (how stressful scheduling was to the staff).

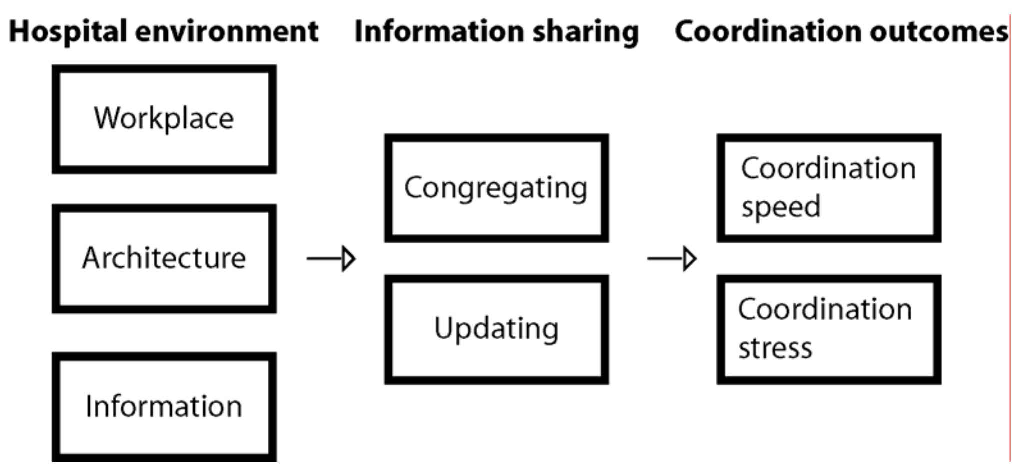


Figure 5-1. Model of the relationship between architecture and coordination.

5.1.1 Hospital Environment Variables

Workplace. The hospital environment factors I measured included the type of hospital (university hospital, affiliated hospital, and unaffiliated hospital), and the type of surgical specialties offered (i.e., surgical organ transplantation, neurosurgery, eye surgery etc.). I included them in early analyses but they did not affect any findings, so I do not discuss them further. The size of the hospital is another potentially important factor, because size could affect the technology in the hospital or the amount of coordination necessary (e.g., distances that people need to travel to get scheduling information). The scheduling load, defined as the number of surgeries per room, should affect how much coordination is necessary. Surgeries per room are a proxy measure for how many times an operating room needs to be prepared for a new surgery each day. For each surgery, nurses, housecleaning staff, anesthesia technicians, and others prepare the operating room. That is, more surgeries per room can lead to more changes in the schedule and more room turnovers that people need to know about.

Architecture. The architecture of a hospital's surgical suites has features at the building level, including the configuration and location of rooms and hallways, and features at the local level, such as the configuration and location of furniture and objects in rooms and hallways. Based on the literature and the previous study, at the building level, I expected the proximity of schedule boards, control desks, and sterile corridors (space adjacency) and the connectivity of these spaces to be positively associated with information sharing (congregating, updating) and coordination outcomes (coordination speed, coordination stress). At the local level, heavy foot traffic around the schedule board and control desk that interferes with people's access to scheduling information may be negatively associated with information sharing and coordination outcomes. By contrast, more space for people to gather immediately around the schedule board, and more reasons people have for hanging around the area around the schedule board, should be positively associated with information sharing and coordination outcomes.

My field studies suggested the need for sufficiently spacious pause locations for people to congregate around the schedule board and control desk. Therefore, I predicted that more spacious pause locations would be positively associated with more information sharing and coordination outcomes. In the previous study, one schedule board was located in a narrow hallway and thus limited the number of people that could read it without obscuring the view for others. In addition, I found in the field studies that pause locations around the whiteboard and control desks that supported multiple compatible activities were associated with more frequent congregating. For example, placing a bench facing scheduling boards that encouraged people to sit, change their shoes, discuss the schedule, and wait for patients was positively associated with congregating among different groups and serendipitous coordination opportunities. Therefore, I predicted that the presence of seating areas around schedule boards would be positively associated with information sharing and coordination outcomes.

Information. The information environment includes the synchronous and asynchronous tools that people use to communicate, both formally and informally, about the schedule. All the surgical suites in the field studies used a mix of technologies. Staff used manual or electronic schedule boards along with computer systems for surgical suite schedule and billing, phones, cell phones, pagers, and walkie-talkies. An important aspect of schedule boards regards the types of information displayed and what technology used to display this information. In the field studies, I noticed that what information was on a scheduling whiteboard was associated with who updated and paused around the whiteboard. Three conditions were associated with increased information available for those congregating around the whiteboard and control desk. First, the schedule board placed in a staff-only location where people did not have to worry about violating HIPPA laws by revealing patient information to visitors or the public. Second, furniture oriented to increase exposure to the schedule board. Third, sufficient surfaces available to display relevant scheduling information. The surface of space available for information display, both around the schedule board and on the schedule board itself, can create constraints associated with information sharing and coordination outcomes.

The type of display available to present information manual schedule board versus electronic display, may affect people’s access to scheduling information. Electronic schedule boards allow multiple instances of networked electronic schedule boards throughout the hospital. The greater the number of electronic displays, however, the more distributed groups may become, thus reducing informal interaction. For example, in a hospital with manual schedule boards, the charge nurse and charge anesthesiologist typically meet around the schedule board to discuss schedule changes. With an electronic display, these meetings may become more infrequent and thus there may be less information exchange between charge nurse and charge anesthesiologist.

Electronic boards do not always show the same information as manual boards. For example, some commercial electronic schedule boards show only patient and surgeon information. Omitting nursing and anesthesia staff information may encourage multiple boards and thus complicate coordination. Workers in two of the four surgical suites observed in the field study were optimistic that replacing manual schedule board with an electronic counterpart would improve coordination and reduce the effort necessary to coordinate. However, because of the separation of information, information sharing and coordination outcomes might not improve despite the use of electronic schedule boards.

Another issue is that the accuracy of the scheduling information displayed can vary according to the type of system used. For example, posting surgery status information about ongoing surgeries is useful with real-time surgery logging. In very difficult surgeries or when understaffed the surgical record may be filled out after the surgery is over. Likewise, automatic patient tracking systems that display patient location provide useful information for scheduled cases. However, equally important is information about events that may affect the schedule (i.e., incoming emergencies, scheduled surgeries likely to be delayed or cancelled). With current electronic schedule boards systems, key decision makers often delegate the task of updating schedule changes to someone else. Consequently, when delegated updates may appear more slowly on electronic displays compared to when the decision makers update.

5.1.2 Information Sharing

Congregating. Congregating around the schedule board and control desk encourages surgical staff to share information. When different groups gather, they are likely to become aware of each other's activities and can anticipate coordination problems that may arise from changes to the schedule. Thus, the schedule board can be updated more frequently and increase the coordination speed in the surgical suite. Faster coordination speed may allow surgical staff more time to adapt to schedule changes and thus reduce coordination stress.

Updating. Updating of the schedule board takes both spoken and written form. Spoken updates are ephemeral in nature, benefit those who are present directly, and may trigger further updating of the schedule. Written updates on schedule boards benefit both those who are present and those that see them later. Typically, in the surgical suite setting, given the tightly coupled nature of work among groups, groups discuss schedule changes. Hence, discussion precedes updating the schedule board. Thus, discussing and updating the schedule board creates a virtuous cycle that attracts staff to check the schedule board. Congregating around the schedule board is necessary to update the schedule board and creates coordination opportunities. In turn, with increased congregating around the schedule board, coordination speed increases and coordination stress decreases.

5.1.3 Coordination Outcomes

Finally, I examined the effects of hospital environment factors and information sharing on two outcome measures: coordination speed and coordination stress.

Coordination speed. Coordination speed is how quickly surgical suite staff learn about changes to the schedule. In my previous field study, workers in surgical suites with better coordination described the information displayed on the schedule board as accurate, updates between teams as timely, and the amount of information displayed on the schedule board as complete. I argue that a hospital environment shaped to support more complete information and information sharing will be associated with greater successful coordination speed.

Coordination stress. Faster coordination among staff members allows each staff member to organize his or her work and proactively respond to schedule changes. For example, operating rooms, surgical equipment, and anesthesia drugs must be prepared prior to a surgery. Operating rooms need to be setup for each surgery according to the patient's specific surgical procedure (i.e., surgery setup for a left femur surgery differs from that for a right femur surgery). Likewise, anesthesia drugs and surgical kits are prepared individually for surgery patients and procedures. Anticipating a schedule change allows staff to avoid scrambling to set up a room, find surgical equipment, and drawing anesthesia drugs. The surgical suite staff is under pressure to minimize the turnover time between surgeries and provide safe patient care. Thus, time pressure resulting from untimely coordination can increase coordination related stress, and coordination speed should reduce coordination stress. Table 5-1 is a summary of the hypotheses.

Table 5-1. Summary of hypotheses.

Independent variables	Congregating	Updating	Coordination Speed	Coordination Stress
Architecture: Space adjacency Visibility, audibility, readability, easy updates	+	+	+	-
Architecture: Connectivity Centrality, distance to schedule board	+	+	+	-
Architecture: Access area Gathering, traffic free, barrier free, seating	+	+	+	-
Information Amount displayed, notices around, surface area of schedule board	+	+	+	-
Information sharing: congregating		+	+	-
Information sharing: updating	+		+	-
Coordination speed				-

5.2 Method

I tested the hypotheses above with an anonymous mail survey distributed to surgical suite directors (typically nurses). The survey asked respondents to describe their architecture, information, and work environment. It also asked them about congregating and updating of the schedule, coordination speed, and coordination stress.

5.2.1 Sample and Recruiting

The survey participants were listed in the SK&A Information Services (Stuart Krasney and associates) list (http://www.skainfo.com). This list contains 3828 operating room directors from hospitals across the United States.[10] Surveys were sent to a random sample of 1200 members of this list. The participants were sent a cover letter explaining

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[10] The American Hospital Association lists the number of registered hospitals in the United States as 5,708 in November 2008. *http://www.aha.org/aha/resource-center/Statistics-and-Studies/fast-facts.html* accessed February 18, 2009. An analyst from the SK&A Information Services company said that their database includes 95-98% of all hospitals and surgical suites in the United States. The SK&A hospital mailing list continuously updated and verified every six months. SK&A claims to have the most comprehensive and accurate list of hospitals.

the purpose of the survey, the survey booklet, and a business reply envelope (Appendix 1). Of the 1200, 16 envelopes were returned as undeliverable. One hundred and thirty-five surgical suite directors returned the survey (11.4% response rate). Due to the high cost of using the mailing list more than once, I was able to contact the respondents only once. Low response rates may entail non-response error when respondents differ from non-respondents (Dillman 1991). However, response bias is less likely even with low response rates if respondents and non-respondents are similar (Dillman 1978, 2000). Dillman (1978) notes that response rates of 70% and higher are achievable but require multiple contacts with participants.

I investigate three sources of response bias: geographic area of respondents, respondents' hospital type, and hospital size measured as number of hospital beds. Table A2-1 in Appendix 2 shows the percentage of surgical suites by regional area for three samples (except for 17 with no postmarks): (a) the 118 returned postmarked surveys; (b) the sample of 1200 surgical suite directors randomly selected to be mailed a survey packet; and (c) the complete list of surgical suite directors on the SK&A mailing list. Across the three lists, the distribution of respondents by regional area is similar (Table A1-1). Thus, I did not detect response bias based on geographic region of hospitals.

Table 5-2 shows the type of hospital for survey respondents, the 1200 surgical suite directors mailed a survey, and the complete list of surgical suite directors. The percentages for hospital type were similar across all three groups. Thus, I did not detect response bias based on type of hospital by respondents.

In the survey, I measured hospital affiliation with a self-report item regarding hospital affiliation with academic institutions. The majority, 81 out of 113 hospitals in the sample, were general acute care hospitals. Most of the general acute care hospitals (58 hospitals) were not-affiliated with an academic institution or university hospitals (Appendix 2). Table 5-2 also shows hospital type by number of hospital beds for survey respondents, mailing sample, and complete list of surgical suite directors. The percentages of hospital type and average number of beds suggest there is no response bias or coverage error. In sum, for the measures I was able to check, there does not seem to be a strong bias in the sample.

In the survey, I asked about hospital affiliation with academic institutions. The majority, 81 out of 113 hospitals in the sample, were general acute care hospitals. Most of the general acute care hospitals (58 hospitals) were unaffiliated with an academic institution or university hospitals (Appendix 2).

Table 5-2. Hospital type and number of beds for the survey respondents, the survey sample sent surveys, and the complete mailing list.

Hospital type	Survey respondents[11] N=113			Random sample sent survey N=1200			Complete list N=3827		
	Type	**N**	**Beds**	**Type**	**N**	**Beds**	**Type**	**N**	**Beds**
Critical care access	7.08%	8	23.50	6.33%	76	23.14	6.51%	249	23.78
Children	5.31%	6	170.00	1.83%	22	176.32	1.62%	62	194.92
General acute care	71.68%	81	231.48	73.83%	886	222.02	72.56%	2777	227.00
Geriatric care	0%	0	0	0.08%	1	16.00	0.05%	2	20.50
Long term acute care	7.96%	9	24.67	10.67%	128	28.76	11.24%	430	30.19
Military	1.77%	2	108.00	0.92%	11	106.18	0.76%	29	119.69
Mental health	0%	0	0	0%	0	0	0.05%	2	523.00
Nursing homes	0.88%	1	50.00	0.75%	9	65.22	1.33%	51	90.08
Osteopathic	1.77%	2	297.50	0.67%	8	217.13	0.63%	24	189.75
Prisons	0%	0	0	0.08%	1	112.00	0.08%	3	146.67
Rehab centers	0%	0	0	0.25%	3	135.67	0.18%	7	125.14
Substance abuse	0%	0	0	0.08%	1	98.00	0.03%	1	98.00
University/teaching	1.77%	2	502.50	1.92%	23	440.78	2.35%	90	493.81
Veteran admin	1.77%	2	267.50	2.58%	31	287.77	2.61%	100	286.46
Total	100%	**113**		100%	**1200**		100%	**3827**	
Mean			**199.25**			**191.01**			**195.87**

5.2.2 Materials

I asked respondents to describe one surgical suite even if they directed more than one. The survey consisted of 73 questions about the respondents' surgical suite. Topics included information about the person filling out the survey, the work done in his/her suite, how the surgical suite dealt with surgical schedule changes, the surgical schedule

[11] Of the 135 survey respondents, the hospital types for 22 respondents are missing in the dataset. Hence, I calculated the response rate by type of hospital for the 113 hospitals identified.

board most in use, activities around this board and activities around the control desk. I also asked them to evaluate one schedule board and control desk. I formatted questions into a 7 by 8 ½ inch booklet for mailing (Appendix 1).

5.2.3 Measures

Below, I describe the variables and measures used in the study. Table 5-3 shows all the questions used in the measures. I used 5-point Likert scales in most questions ranging from strongly disagree to strongly agree.

5.2.4 Workplace

Hospital beds. As noted earlier, the SK&A list showed that the number of beds in participants' hospitals ranged from 17 to 695 (Mean 199, SD 164. 61). I used a log10 transformation because the distribution had a positive skew.

Surgeries per room. I asked respondents to indicate how many surgeries their surgical suite completed each day, etc., and the number of operating rooms used per day. I calculated surgeries per room by dividing total surgeries by total rooms.

Type of hospital. I asked respondents what type of hospital they worked in (i.e., university hospital, affiliated, non-affiliated). The SK&A mailing also listed the type of hospital (i.e., general acute care, military, veteran administration, children, etc). Because the preponderance of respondents from non-affiliated (private) hospitals, I did not use this measure in the analyses. Likewise, the majority of respondents were in general critical care hospitals; hence, I did not use this measure in analyses (see Appendix 2).

Surgical specialties. I asked participants to indicate the type of surgical services provided on a weekly basis (i.e., cardiac surgery, general surgery, organ transplantation, vascular surgery, etc). I calculated the total of surgical services present (Mean 7.66 SD 3.33, Min 1, and Max 14).

Role assignments. I asked participants if there was a charge nurse and/or a charge anesthesiologist in the surgical suite. I summed the two items to determine the number of people in supervisory coordination roles. I asked participants who routinely staffed the control desk (i.e., charge nurse, clerk/receptionist, surgical suite nurse, surgical staff, house cleaning, other). I summed the items for the control desk staff.

To measure scheduling load, as in the field studies, I calculated the scheduling load for each unit in two ways: cases per room and schedule changes (add on cases/total cases).

5.2.5 Architecture

Traffic-free areas around the schedule board was measured by asking respondents if foot traffic interfered with schedule board information access, using a 5-point Likert scale ranging from strongly disagree to strongly agree. I inverted the scale such that higher numbers reflected greater freedom from traffic.

Barrier-free areas around the schedule board was measured by asking respondents if there were any physical barriers (i.e. walls, door and furniture) between the surgical suite schedule board and control desk, using a binary yes/no scale. I inverted the responses such that a higher score indicated freedom from barriers.

Access area was measured by two questions: (a) the greatest distance at which the display is legible (using a 5-point scale ranging from two foot or less to more than eight feet) and (b) how many people can comfortably gather around the schedule board (using 5-point scale ranging from 2 or less to 10 or more).

Multiple uses was measured by asking respondents two questions: (a) how often people stop by and sit around the schedule board (using a 5-point Likert scale ranging from never to almost continually); and (b) how often do people drink beverages or eat food around the schedule board? (Using a 5-point Likert scale ranging from never to almost continually). In the field studies, I noted that having chairs and benches around the schedule board and beverage consumption were associated with the presence of multiple uses such as changing shoes, calling for information, and waiting for a patient.

5.2.6 Information

The information environment has two components: communication media practices such as using phones to coordinate and the presence of shared information artifacts such as the schedule board.

To gauge communication practices in the surgical suite I asked respondents how often they coordinated schedule changes using a face-to-face communication and communication media. These items used five point scales ranging from "never" to "almost always." Factor analysis of the responses indicated the presence of three factors (see Table 5-3). From this analysis, I created three scales. The *face-to-face elsewhere scale* consisted of items reflecting face-to-face conversations other than at the schedule board such as in lounges, break rooms, or cafeteria (Cronbach's alpha = .78). *Face-to-face hotspots scale* consisted of three items reflecting face-to-face conversations around the schedule board and around the control desk (Cronbach's alpha = .68). The *media* scale consisted of three questions about use of phone calls, overhead announcements, and pagers/beepers (Cronbach's alpha = .55).

Table 5-3. Communication practice measures and factor loadings.

Measure	Factor Loadings		
	Face-to-face Elsewhere	Face-to-face Hotspots	Media
Face-to-face hallways	**0.86**	-0.06	0.05
Face-to-face elsewhere	**0.82**	0.22	-0.10
Face-to-face lounges, cafeteria, workrooms	**0.78**	0.04	0.30
Face-to-face schedule board	0.17	**0.81**	0.08
Face-to-face control desk	0.13	**0.76**	0.19
Face-to-face schedule board	-0.12	**0.73**	0.18
Coordinate with pager (or beeper)	0.06	0.31	**0.72**
Coordinate with overhead announcements	0.03	-0.02	**0.71**
Coordinate with phone calls	0.10	0.23	**0.64**

Schedule board information displayed. Participants were asked to indicate which of 14 types of information (e.g., time of surgery, patient name, surgeon, procedure, etc.) were available on their surgical suite schedule board. I totaled the number of different types of information available. This variable was normally distributed (mean 8.59, SD 2.20) and thus I used it directly as a measure of information displayed.

Posters around the schedule board. I measured the availability of surfaces to host information by asking participants how much information was around the schedule boards (using a 5-point scale ranging from none to 46 or more items). I asked the same about the control desk.

Schedule board surface. I asked participants approximately what size (i.e., height and width) the schedule board was and what position the board was from the floor. I calculated the surface of the display boards in square inches. Given the positively skewed distribution, I applied a log transformation.

Display type was measured by asking participants to indicate which of a series of pictures of surgical suite displays was most like the one they used in their surgical suite. Options were a handwritten whiteboard, a whiteboard with magnetic strips, a large electronic display, or other (Appendix 2).

Number of displays was measured by asking participants how many of each type of schedule boards are used in their surgical suite (mean 2.20, SD 3.17).[12]

5.2.7 Information sharing

Congregating was measured by asking respondents to estimate the frequency with which people in seven different roles (charge nurse, control desk staff, surgical suite nurses, charge anesthesiologist, anesthesia team members, surgeons and housekeeping staff) congregate around the schedule board, using a five point Likert scale ranging from not at all to frequently during the day. The seven items form a reliable scale (Cronbach's alpha = .78). The same set of questions was asked about congregating around the control desk (Cronbach's alpha = .79).

Updating activity. Updating activity was measured by asking respondents to estimate the frequency with which people in four key coordination roles (charge nurse, charge anesthesiologist, surgical suite nurses and anesthesia team members) updated the schedule display board (using a five point Likert scale ranging from not at all to almost

[12] Given the positive skew in the distribution, I recoded the displays as 1, 2, and 3 or more displays.

continually during the day). The items formed a reliable scale (Cronbach’s alpha =.65) and were averaged to create the updating activity measure.

5.2.8 Coordination Outcomes

I measure coordination indirectly with two related measures associated with information sharing observed in the field: (a) coordination speed (b) coordination stress.

Coordination speed, or the amount of time it takes different people to learn about changes to the surgical suite schedule, was measured by asking respondents how quickly each of five categories of workers (charge nurse, charge anesthesiologist, surgeons, surgical suite nursing staff and anesthesia staff) find out about schedule changes. I used a five-point Likert scale ranging from more than an hour to almost immediately. The five questions load together and have Cronbach's alpha = .84. I created the coordination speed scale by averaging the five scores.

Coordination stress was measured with five questions about the effort and stress required to learn about surgical suite schedule changes. The five items loaded together (Cronbach’s alpha = .73). I developed a self-report coordination stress scale by averaging the five values.

Table 5-4. Measures, variables, and survey questions analyzed. The variables used in regression analyses are numbered.

Variables	Question
Workplace (Controls variables) Hospital size 1. log hospital beds[13]	How many beds are in the hospital? (number of hospital beds)
Scheduling load 2. surgeries/room	On average, how many [operating rooms, surgeries] are [used, completed] each day? (surgeries completed / rooms)
hospital affiliation	Academic affiliations. Check one. [university hospital, affiliated with another academic institution, not affiliated with an academic institution]
surgical services	Which surgical services are provided each week? Check all that apply. [cardiac, general, interventional radiology, neurosurgery, ophthalmology, oral/maxillofacial, orthopedics, otorhinolaryngology, pediatric, plastic/reconstructive, thoracic, transplantation, vascular, urology, other] (sum of services offered)
Architecture[14] Space adjacency 3. visibility, binary audibility, binary readability 4. easy updates, binary	People at the schedule board and control desk can see each other. (1 = strongly disagree to 5 = strongly agree) Conversations at the schedule board can be overheard at the control desk. (1 = strongly disagree to 5 = strongly agree) How far can you stand from the schedule board and still read most of it? (1 = two feet or less, 5 = eight feet or more) The surgical suite schedule board is easy to update. (1 = strongly disagree to 5 = strongly agree)
Connectivity 5. log distance schedule board & sterile corridor 6. schedule board centrality	Approximately how far is this schedule board from the closest sterile corridor? (distance in feet) Is this schedule board in a sterile corridor or in a main hallway connected to a sterile corridor? (no = 0, yes = 1)
Access areas (around schedule board) 7. gathering	How many people can comfortably gather around the schedule board? (1 = two persons or less to 5 = ten or more persons)

[13] Variables with skewed distributions were logged.
[14] Because visibility, audibility, and ease of updates, were positively skewed, and a log transformation was not sufficient to unskew the data, I recoded the data to be binary yes/no items (1-3 as 0, and 4-5 as 1).

8. traffic-free, binary	Foot traffic interferes with people reading the schedule board. (1 = strongly disagree to 5 = strongly agree; Inverted)
9. barrier-free, binary	Are there any physical barriers (i.e., walls, doors, or furniture) between this schedule board and the control desk? (1 = yes, 0 = no; Inverted)
10. sitting snacking	How often do people stop by and sit around the schedule board? (1 = never to 5 = almost continuously) How often do people drink beverages or eat food near the schedule board? (1 = never to 5 = almost continuously)
Information Communication practices 11. face-to-face at hotspots (scale) 12. face-to-face elsewhere (scale) 13. media (scale)	On the day of surgery, how often do people coordinate changes to the schedule with face-to-face conversations at the [schedule board, control desk]? (1 = never to 5 = almost always) On the day of surgery, how often do people find out about schedule changes by checking information posted on the schedule board? (1 = never to 5 = almost always) On the day of surgery, how often do people find out about schedule changes with face-to-face conversations… in [hallways; workrooms, cafeterias, and break rooms]? (1 = never to 5 = almost always) On the day of surgery, how often do people coordinate changes to the schedule using [pager (or beeper), phone calls, overhead announcements]? (1 = never to 5 = almost always)
Schedule board 14. amt. information	Which schedule board is most like the one(s) used in your surgical suite? How many of each type of schedule boards are in your surgical suite? (number) What information is available on this schedule board? Check all that apply. [time of surgery, OR#, patient name/initials, etc] (sum of types of information posted)
15. notices around, binary[15]	How many papers, posters, post-it notes, or contact lists are posted around the schedule board? (1 = none to 5 = 31 items or more)

[15] Given the negative skew in the distribution, and a log transformation was not sufficient to unskew the data, I recoded it the data into a binary few items, many items (1-3 as 0, and 4-5 as 1).

16. log10 surface area	Approximately what size and position is this surgical suite schedule board? [height, width in inches] Distance from the bottom of this schedule board to the floor [distance in inches]
Information sharing 17. Congregating (scale)	How often are the following persons around the surgical suite schedule board each day? [charge nurse, control desk staff, surgical suite nurses, charge anesthesiologist, anesthesia team, surgeons, housekeeping staff] (1 = never to 5 = almost continuously)
18. Updating (scale)	Who updates the schedule board each day and how often do they update it? [charge nurse, control desk staff, surgical suite nurses, charge anesthesiologist, anesthesia team, surgeons, housekeeping staff] (1 = never to 5 = almost continuously)
Coordination outcomes 19. Coordination speed (scale) 20. Coordination stress (scale)	On the day of surgery, how quickly do the following people learn about changes to the schedule? [charge nurse, charge anesthesiologist, surgeons, surgical suite nursing staff, anesthesia staff] (1= never to 5= almost continuously) Rate how much you agree or disagree with the following statements about your surgical suite. There are few schedule changes each day. (1 = strongly disagree to 5 = strongly agree; inverted) People adapt easily to schedule changes. (1 = strongly disagree to 5 = strongly agree; inverted) It takes little effort to update the schedule board. (1 = strongly disagree to 5 = strongly agree; inverted) People have to run around to learn about schedule changes. (1 = strongly disagree to 5 = strongly agree; inverted) Schedule changes are stressful. (1 = strongly disagree to 5 = strongly agree; inverted)

5.3 Results

The results are as follows. First, I provide descriptive data about the respondents. Next, I describe the statistical approach used for testing the hypotheses. Then I describe preliminary analyses of control variables, and then present the main analyses, a series of hierarchical regressions to test my hypotheses. I then present an analysis that compares surgical suites with manual schedule boards and electronic schedule boards.

5.3.1 Descriptive Sample Statistics

The survey respondents selected the role that best described them: administrator, operating room nurse, anesthesiologist, surgeon, or other. I coded the entries under the category "other" into three categories based on the job title provided: director, manager, and other. The category "other" contained all job titles that did not include director or manager. Almost half of the survey respondents described their role as administrator. Close to 45% of the respondents described their role as nurse, director, or manager (Table 5-5).

Table 5-5. Occupational roles of survey respondents as a percent of total respondents.

Administrator	**Nurse**	**Surgeon**	**Director**	**Manager**	**Other**
48.46%	16.92%	0.77%	15.38%	13.08%	5.38%

Type of surgical suite. Survey participants reported that their surgical suites performed a variety of surgical services on a weekly basis (e.g., Cardiac, General, Interventional Radiology, Neurosurgery, Plastic Reconstructive, etc.; see Table 5-6).

Surgical suites used schedule boards, electronic boards, and paper to display the schedule. Participants from surgical suites without a schedule board reported using paper printouts of the schedule, or a logbook with the schedule. Table 5-7 shows for each type of schedule used number of operating rooms, number of hospital beds, and surgeries per room. Surgical suites with electronic displays had the most operating rooms, and hospital beds.

Table 5-8 shows differences in the hospitals using different forms of information artifacts to share schedule information. I applied a log 10 transformation to variables with skew distributions. In general, the statistically significant correlations ranged from low values to medium values.

Table 5-6. Frequency of surgical services present (n=135).

Surgical service	Count
General service	132
Orthopedics service	123
Urology service	101
Otorhinolaryngology service	88
Ophthalmology service	84
Vascular service	72
Plastic / reconstructive service	66
Pediatric service	60
Oral maxillofacial service	59
Neurosurgery service	55
Thoracic service	55
Other service	50
Cardiac service	37
Interventional radiology service	22
Transplantation service	12

Table 5-7. Workplace characteristics of hospitals using paper, manual, and electronic schedule boards.

	Mean operating rooms	S.D.	N	Mean beds	S.D.	N	Surgeries per room	S. D.	N
Paper schedule	6.71	7.74	14	209.78	209.90	9	3. 20	1.35	17
Schedule board	6.70	4.22	74	176.60	127.93	64	3.79	1.33	75
Electronic board	17.45	6.84	11	438.18	170.63	11	3.15	1.26	11

5.3.2 Statistical Approach

I used hierarchical multiple regression to test each of the hypothesized relationships among input variables, information sharing and coordination outcomes. I ran one set of regressions for each of the four dependent measures—congregating around the schedule board, schedule board updating, coordination speed, and coordination stress. I chose regression because there are no experimental conditions. I used hierarchical regression because it allows me to see how much each block of variables (where blocks are roughly equivalent to the concepts of interest) contributes to the dependent measure.

Table 5-8. Descriptive statistics of variables used in the analyses (Appendix 3). Please Note. Means are raw (not log means). See Table 5-4 for variable definitions. * = p < .05, ** = p < .01

Variables	Mean	S.D.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Workplace (Controls variables)																					
Hospital size																					
1. Hospital beds	199.15	166.25	-.11	.06	-.14	.04	-.10	.09	.00	.04	.18	.09	-.04	.22*	.03	-.16	.00	.09	.18	.11	-.08
Scheduling load																					
2. surgeries/room	3.65	1.39		.14	.13	-.14	.13	-.04	.08	.14	.07	-.11	-.03	-.16	.19	.03	.24*	.01	-.14	-.01	.05
Architecture																					
Space adjacency																					
3. visibility, binary	.82	.39			-.10	.11	-.15	.07	-.12	.35**	.18	.09	-.10	-.03	.08	.16	.06	.16	.13	.14	.03
4. easy updates, binary	.96	.19				-.10	.18	.11	.15	.06	.16	.25*	-.14	.06	-.03	.07	.16	.11	-.10	.14	-.15
Connectivity																					
5. log distance schedule board & sterile corridor	.83	.37					-.29**	-.16	-.20**	-.09	.14	.10	.18	.04	.12	.10	-.12	.00	.07	.03	.02
6. schedule board centrality, binary	.85	.53						-.04	.12	.10	-.01	-.03	-.11	-.06	-.06	-.09	.08	-.06	-.12	-.14	.05
Access areas (around schedule board)																					
7. gathering	3.18	1.20							-.04	.04	.06	.13	-.22*	.07	.12	.02	.24*	.18	.00	.08	-.02
8. traffic-free	3.42	1.21								.03	-.30**	-.12	-.06	-.12	-.08	-.22*	-.04	-.11	.00	.26**	-.45**
9. barrier-free, binary	.64	.48									-.02	.07	-.2*	-.08	-.19*	-.01	.09	.10	.07	.22*	-.10
10. sitting	3.32	1.37										.31**	-.13	.12	.37**	.14	.22*	.30**	.14	-.09	.26*
Information																					
Communication practices																					
11. face-to-face at hotspots	3.14	.80											.20*	.33**	-.01	-.03	.15	.09	.09	.10	-.03
12. face-to-face elsewhere	3.71	.65												.20*	.01	-.08	-.20	-.10	.14	.01	.21*
13. media	2.83	.79													-.10	.11	.25*	.21*	.17	-.10	.23*
Schedule board																					
14. amt. information	8.59	2.21														.11	.28**	.17	.03	-.12	.21*
15. notices around, binary	.67	.47															.10	.07	.02	.08	.15
16. surface area sq. inches	3750.03	2632.26																.26*	.13	-.03	.11
Information sharing																					
17. Congregating	3.48	.72																	.45**	-.01	.29**
18. Updating	2.47	.90																		.09	.11
Coordination outcomes																					
19. Coordination speed	4.04	.62																			-.45**
20. Coordination stress (R)	2.69	.67																			

Before entering the data, I checked the correlations among the measures shown in Table 5-9. As can be seen, visibility and audibility were highly correlated. To prevent multicollinearity in the regression models reported in the next section, I selected visibility to represent space adjacency. Visibility had the greatest effect on the regression models when I tested the three measures together, pairwise, and individually. Readability was not significant in any regression model. Both visibility and audibility were significant variables when alone in the regression, but when I ran visibility and audibility together visibility was a significant coefficient and audibility was not.

Table 5-9. Partial correlations between visibility, audibility, and readability controlling for hospital beds and surgeries per room for surgical suites with both a schedule board and a control desk (p<.01)**

Variables	Visibility	Audibility	Readability
Visibility	1	.72**	.58**
Audibility		1	.44**
Readability			1

For each analysis, the first block of variables entered was comprised of the two control variables, surgeries per room and log number of beds. Block 2 contained variables pertaining to the architecture, including space adjacency, connectivity, and access areas. Block 3 contained variables pertaining to the information environment, including communication practices schedule board characteristics (Table 5-10)[16].

I added additional blocks to specific regressions to test various components of the model (e.g., congregating was a predictor for coordination speed).

The underlying theoretical framework, derived from the field studies, specifies relationships between variables and thus the order of the blocks.

The regressions omit any respondent with any missing data. Of the 104 respondents with control desks and schedule boards, 70 respondents had no missing data. I ran the models with imputed means for missing data. The results are the same.

[16] For a detailed analysis with more individual blocks, each with fewer variables at a time see appendix 4. For analysis of control desk alone, and schedule board and control desk together see appendix 5.

Table 5-10. Regression variable blocks. Dependent variables are congregating, updating, coordination speed, and coordination stress. [1]

Block	Variables Entered
1: Workplace (control variables)	Number of beds Number of surgeries per operating room.
2: Architecture	Visibility between schedule board area and control desk (adjacency) Ease of updating the schedule board (adjacency) Distance to the sterile corridor (connectivity) Centrality with respect to the main corridor (connectivity) Traffic free area around schedule board (access area) Number of people who can gather around the schedule board (access area) Barrier free area around schedule board Sitting around schedule board
3: Information	Face-to-face conversation outside schedule area (comm.. practices) Face-to-face conversation in hotspots (comm.. practices) Mediated communication (comm.. practices) Types of information posted on the schedule board (schedule board) Posters around the schedule board (schedule board) Schedule board size (lg10) (schedule board) Electronic schedule board (dummy variable)

[1] **See Table 5-4 for variable definitions.**

5.3.3 Control Variables

The field data from the Pennsylvania and Maryland field studies (Chapters 2 and 3) led me to expect that the work setting (hospital affiliation with a university, type of hospital, type of surgical suite, kind of surgical specialties present, and role assignments) and the scheduling load (i.e., number of cases per room, number of add-on cases per cases completed) might affect coordination outcomes, independent of the architecture and information environment variables of interest. To test this idea, I ran four regressions with workplace measures as the independent variables and congregating, updating, coordination speed, and coordination stress as the dependent variables.

Hospital affiliation and hospital type alone did not significantly improve prediction. Therefore, I did not use these as control variables. Hospital affiliation did not improve prediction because only 6.2% of respondents were in university hospitals (see Appendix 2). Likewise, hospital type did not improve prediction because the 61% of the hospitals were general acute care, and for 15% of the respondents, hospital type was not specified (Appendix 2). I found that entering the other potential control variables (surgeries per room, number of displays, log 10 number of beds, and log 10 surgical specialties per room) in a block did not result in significant regression models for congregating (R^2 = .08), updating (R^2 = .09), coordination speed (R^2 = .03), and coordination speed (R^2 = .04). Hospital size measured with hospital beds as an independent variable did result in a significant model for congregating as a dependent variable. Thus, to control for the workplace in the models that follow I entered a control variable proxy for hospital size, number of hospital beds. My previous study suggested that coordination load measured as surgeries per room might be very important in coordination. Therefore, despite the lack of effect by itself, I used surgeries per room (a proxy for scheduling load) as a control variable in the models.

5.3.4 Main Analyses

Overall, there were 135 respondents. However, to test the architecture and information hypotheses, I needed to examine the data from respondents who reported both a control desk and at least one schedule board. Of the 135 respondents, 104 had both a control desk and at least one schedule board. For the analyses in this section, I used the 70 cases with complete data.

Predicting congregating. The first set of regression models had congregating around the schedule board as an outcome measure. I entered blocks 1-3 as in Table 5-10; block 4 consisted of schedule updating.

The control variables alone (Model 1) did not account for any variance in congregating (R^2 = .04, *ns*). Adding architecture variables (Model 2) led to a significant improvement in prediction (R^2 = .37; F Change [8, 56] = 3.68, p. = .002). Further adding information variables (Model 3) led to additional improvement in prediction (R^2 = .56; F Change [7, 49] = 2.97, p. = .01). Finally, adding the other information sharing variable, updating, further improved prediction (R^2 = .59; F Change [1, 48] = 4.17, p. < .05).

I examined the significance of each variable in the final model (Table 5-11). Within the architecture block, visibility between the schedule board and control desk is a significant effect associated with more congregating (t = 2.48, p = .01). There is also a trend for more congregating to occur around schedule boards that accommodate more people standing around them ($t = 1.66$, $p = .10$).

Two features of the information environment, both communication practices, were significantly associated with congregating. When staff coordinated schedule changes via face-to-face communication in places other than around the schedule board and control desk (e.g., cafeterias, break rooms, hallways), congregating around the board was significantly lower ($t = -2.80$, $p < .01$). Also, when staff coordinated schedule changes using media (e.g., cell phones and pagers), congregating around the schedule board was significantly higher ($t = 2.88$, $p < .01$).

Finally, when schedule boards were updated more frequently, congregating around these boards was greater ($t = 2.04$, $p < .05$).

The gist of these results is that architecture and information variables, taken together, predict congregating. It appears that visibility of information and people, and communication among people, are the most important factors associated with congregating around the schedule board. Congregating and updating are associated, perhaps because when someone is updating the schedule, others are likely to stop by to see the change, and according to the previous study, people are making decisions that they need to discuss before updating and when updates are made.

Predicting schedule board updating. The second set of models had updating as the outcome measure. The first three blocks were as outlined in table 5-10. In the fourth block, I placed updating as an independent variable.

For updating, control variables alone (Model 1) were poor predictors ($R^2 = .01$, *ns*). Adding architecture variables (Model 2) failed to improve the model significantly ($R^2 = .09$; *ns*). Adding information environment variables (Model 3) likewise failed to improve the model ($R^2 = .22$). However, adding congregating to the model (Model 4) did significantly improve prediction ($R^2 = .28$; F Change [1, 48] = 4.17, p. < .05). See Table 5-12.

Looking at each variable in the final model, the only significant effect was that updating occurred more frequently when staff congregated more often around schedule boards ($t = 2.82$, $p < .01$). Marginally, more updating activity was associated with face-to-face discussion schedule changes in workrooms, hallways, cafeterias, and break rooms (t=1.82, p=.08).

In sum, these analyses show that architecture and information do not predict updating. One explanation for this is that the task of updating the schedule is mandated, and has to occur no matter what the environment. Of course, updating in a poor environment could lead to slower coordination speed and greater stress, addressed in the next analyses.

Predicting coordination speed. The third set of models used coordination speed—measured as the average amount of time it takes people in different roles to find out about schedule changes—as the outcome measure. The first three regression models are the same as those above. In the fourth model, I added the two information-sharing variables: congregating and updating.

The control variables alone (Model 1) did not account for any variance in congregating (R^2 = .01, *ns*). Adding architecture variables (Model 2) led to a significant improvement in prediction (R^2 = .32; F Change [8, 56] = 3.15, p. = .005). Adding information environment variables (Model 3), did not lead to further improvement in prediction (R^2 = .40; F Change [7, 49] = 1.04, *ns*). Adding the two information sharing variables, congregating and updating activity (Model 4), likewise did not improve prediction (R^2 = .41; F Change [2, 47] = .09, *ns*). See Table 5-13.

In the final model, the frequency with which people sat around the schedule board was marginally negatively associated with how quickly they found out about schedule changes (t = -1.84, p = .07). It is possible that people sat at the schedule board to wait for information, in units where there was more uncertainty about the schedule. If so, then the association would be negative. Thus, one would not want to remove the benches, and induce people to go elsewhere because they might miss important updates to the schedule. I saw this situation arise in a trauma unit in Maryland, in my previous study.

Predicting coordination stress. The fourth set of models had coordination stress as an outcome measure. I expected that greater coordination speed would reduce coordination stress. The first four models were the same as in the previous analysis. In the fifth model, I added coordination speed as a predictor variable.

The control variables alone (Model 1) again accounted for virtually no variance in congregating (R^2 = .03, *ns*). Adding architecture variables (Model 2) led to a significant improvement in prediction (R^2 = .31; F Change [8, 56] = 2.79, p. = .01). Adding information environment variables (Model 3), also improved the model fit (R^2 = .50; F Change [6, 50] = 3.13, p = .01). Adding the two information sharing variables, congregating and updating activity (Model 4), did not improve prediction (R^2 = .51; F Change [2, 48] = .42, *ns*). Finally, adding coordination speed to the model significantly improved prediction (R^2 = .60; F Change [1, 47] = 11.04, p = .002)

Several individual variables were significant. When the area around the schedule board was traffic free, staff reported lower stress (t = -2.6, p = .01). Also, when staff coordinated schedule changes using face-to-face communication in places like cafeterias, break rooms, and hallways, self-reported stress was higher (t = 1.9, p = .05). This finding may mean that finding out about schedule changes without the benefit of the schedule board overview increases stress. Another explanation may be that discussing schedule changes throughout the surgical suite indicates the lack of dedicated coordination location. Two characteristics of the schedule board had significant effects. When more information about surgeries was displayed on the board, self-reported stress was lower (t = -2.1, p < .05) but when the overall dimensions of the board were greater, self-reported stress was higher (t = 1.9, p = .05). I speculate that large boards not used to provide additional information per room add to stress rather than reduce it. Lastly, people reported less stress when changes to the schedule were communicated more rapidly; that is, more coordination speed predicted lower coordination stress (t = -3.3, p = .003). See Table 5-14 for the unstandardized regression coefficients for the five models tested.

5.3.5 Exploratory Analysis of Electronic Schedule Boards

The number of electronic schedule boards in surgical suites has doubled in the past 6 years from 8% (Gilbert, 2002). I found this statistic to be 17% in the current survey sample. Understanding the differences and similarities of surgical suites with electronic displays and manual schedule boards is critical to the design of the area where such displays are located.

Table 5-11. Regression models predicting congregating around the schedule board. The table reports unstandardized coefficients for each model, followed by standard error in parenthesis. Level of significance for the coefficients is reported as * p<.05, **p<.01, *** p<.005; ****p<.001). The table data regard 70 surgical suite directors that provided complete data.[1]

	Model 1	Model 2	Model 3	Model 4
Intercept	3.97** (.50)	2.33** (.60)	2.43** (.86)	2.53** (.83)
Control log # hospital beds	-.22 (.19)	-.24 (.17)	-.42* (.19)	-.44** (.18)
# surgeries per room	.05 (.06)	.04 (.06)	.03 (.05)	.04 (.05)
Architectural environment				
Space adjacency				
visibility (yes = 1, no = 0)		.48* (.18)	.45** (.18)	.43* (.17)
easy updates (yes = 1, no = 0)		.44 (.32)	.34 (.31)	.37 (.30)
Connectivity				
centrality (yes = 1, no = 0)		.11 (.16)	.12 (.15)	.13 (.14)
log distance sterile corridor (feet)		.04 (.13)	.17 (.13)	.15 (.13)
Access area gathering schedule (5 point Likert)		.13* (.05)	.09 (.05)	.08+ (.05)
traffic free schedule (yes = 1, no = 0)		-.01 (.06)	-.01 (.05)	-.03 (.05)
barrier free schedule (yes = 1, no = 0)		.06 (.14)	.11 (.13)	.07 (.13)
sitting around schedule board (5 point Likert)		.10* (.05)	.03 (.05)	.03 (.05)
Information environment				
Communication practice				
face-to-face hotspots (5 point Likert)			-.11 (.11)	-.09 (.10)
face-to-face elsewhere (5 point Likert)			-.20* (.08)	-.23** (.08)
media (5 point Likert)			.28** (.09)	.26** (.09)
Schedule board				
log information displayed #			.02 (.03)	.01 (.03)
posters around schedule board (yes = 1, no = 0)			-.03 (.13)	-.02 (.12)
log schedule surface (inches)			.22 (.19)	.19 (.18)
electronic display (yes = 1, no = 0)			-.17 (.18)	-.11(.18)
Information sharing updating (5 point Likert)				.14* (.07)
R^2 (R^2 adjusted)	.04 (.01)	.37 (.26)	.56 (.40)	.59 (.44)
F full model	1.22	3.27**	3.62****	3.87****
Degrees of Freedom	2, 64	10, 56	17, 49	18, 48
R^2 Change	.04	.33	.19	.04
F Change	1.22	3.68***	2.97**	4.17*
DF Change	2, 64	8, 56	7, 49	1, 48

[1] See Table 5-4 for variable definitions.

Table 5-12. Regression models predicting schedule board updating. Unstandardized coefficients are reported for each model; standard errors (S.E.) are given in parenthesis. Level of significance for the coefficients is reported as * p<.05, ** p<.01, *** p<.005, **** p<.001. The table data pertains to the 70 respondents that provided complete data. [1]

	Model 1	Model 2	Model 3	Model 4
Intercept	2.32** (.81)	1.61 (1.13)	-.76 (1.81)	-2.20 (1.89)
Control				
log # hospital beds	.16 (.30)	.02 (.33)	-.11 (.39)	.36 (.39)
# surgeries per room	-.03 (.09)	-.01 (.11)	-.08 (.12)	-.09 (.11)
Architecture				
Space adjacency				
visibility (yes = 1, no = 0)		.37 (.35)	.13 (.37)	-.14 (.38)
easy updates (yes = 1, no = 0)		-.34 (.61)	-.23 (.65)	-.44 (.64)
Connectivity				
centrality (yes = 1, no = 0)		-.11 (.30)	-.03 (.31)	-.10 (.30)
log distance sterile corridor (feet)		.21 (.25)	.14 (.27)	.04 (.27)
Access area				
traffic free schedule (yes = 1, no = 0)		.09 (.11)	.11 (.11)	.12 (.11)
gathering schedule (5 point Likert)		.09 (.10)	.07 (.10)	.02 (.10)
barrier free schedule (yes = 1, no = 0)		.02 (.26)	.23 (.28)	.17 (.27)
sitting around schedule board (5 point Likert)		.07 (.09)	.02 (.10)	-.00 (.10)
Information environment				
Communication practice				
face-to-face hotspots (5 point Likert)			-.10 (.23)	-.04 (.23)
face-to-face elsewhere (5 point Likert)			.20 (.17)	.32+ (.18)
media (5 point Likert)			.14 (.20)	-.03 (.21)
Schedule board				
log # information displayed			.10 + (.06)	.09 (.06)
posters schedule board (yes = 1, no = 0)			.09 (.27)	.10 (.27)
log10 schedule surface (inches)			.29 (.39)	.16 (.39)
electronic display (yes = 1, no = 0)			-.47 (38)	-.37 (.29)
Information sharing				
congregating (yes = 1, no = 0)				.59** (.29)
R^2 (R^2 adjusted)	.01 (-.02)	.09 (-.07)	.22 (-.06)	.28 (.01)
F Full Model	.24	.55	.79	1.03
Degrees of Freedom	2, 64	10, 56	17, 49	18, 48
R^2 Change	.01	.08	.13	.06
F change	.24	.63	1.13	4.17*
DF Change	2, 64	8, 56	7, 49	1, 48

[1] **See Table 5-4 for variable definitions.**

Table 5-13. Regression models predicting coordination speed. Unstandardized coefficients for each model are reported, followed by standard errors in parenthesis. Level of significance for the coefficients is reported as * p<.05, **p<.01, *** p<.005; ****p<.001). The table data pertains to the 70 surgical suite directors that provided complete data.[1]

	Model 1	Model 2	Model 3	Model 4
Intercept	4.08** (.58)	3.33** (.69)	3.05* (1.11)	2.99* (1.24)
Control				
log # hospital beds	-.08 (.21)	-.23 (.20)	-.27 (.24)	-.26 (.26)
# surgeries per room	.03 (.07)	.00 (.07)	-.01 (.07)	-.01 (.07)
Architecture				
Space adjacency				
visibility (yes = 1, no = 0)		.45* (.21)	.32 (.23)	.30 (.25)
easy updates (yes = 1, no = 0)		.67 + (.37)	.47 (.40)	.47 (.42)
Connectivity				
log 10 distance sterile corridor (feet)		.24 (.15)	.19 (.17)	.18 (.17)
centrality (yes = 1, no = 0)		-.30+ (.19)	-.30 (.19)	-.30 (.19)
Access area				
gathering schedule (5 point Likert)		.05 (.06)	.08 (.06)	.07 (.07)
traffic free schedule (yes = 1, no = 0)		.07 (.06)	.09 (.07)	.09 (.07)
barrier free schedule (yes = 1, no = 0)		.23 (.16)	.28 (.17)	.27 (.18)
sitting around schedule board (5 point Likert)		-.10+ (.06)	-.12+ (.06)	-.12+(.06)
Information environment				
Communication practice				
face-to-face hotspots (5 point Likert)			.10 (.14)	.14 (.14)
face-to-face elsewhere (5 point Likert)			.05 (.10)	.03 (.12)
media (5 point Likert)			-.05 (.12)	-.06 (.13)
Schedule board				
log # information displayed			.06 (.04)	.05 (.04)
posters around schedule board (yes = 1, no = 0)			.27 (.17)	.27 (.17)
log schedule board surface (inches)			-.11 (.25)	-.13 (.25)
electronic display (yes = 1, no = 0)			.20 (.24)	.22 (.25)
Information sharing				
congregating (5 point Likert)				.04 (.20)
updating (5 point Likert)				.03 (.09)
R^2 (R^2 adjusted)	.01 (-.02)	.32 (.19)	.40 (.20)	.41 (.17)
F Full Model	.24	2.58**	1.95*	1.69+
Degrees of Freedom	2, 64	10, 56	17, 59	19, 47
R^2 Change	.01	.31	.09	.002
F change	.24	3.15***	1.04	.09
DF Change	2, 64	8, 56	7, 49	2, 47

[1] See Table 5-4 for variable definitions.

Table 5-14. Regression models predicting coordination stress. Unstandardized coefficients reported for each model are followed by standard error in parenthesis. Level of significance for the coefficients is reported as * p<.05, ** p<.01, *** p<.005; **** p<.001). The table data pertains to the 70 surgical suite directors that provided complete data.[1]

	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	3.64** (.58)	3.64** (.71)	1.92* (1.03)	1.77 (1.13)	2.91** (1.10)
Control					
log #hospital beds	-.26 (.21)	-.15 (.21)	-.03 (.21)	-.06 (.23)	-.04 (.21)
# surgeries per room	-.07 (.07)	-.01 (.07)	-.02 (.07)	-.01 (.07)	-.02 (.06)
Architecture					
Space adjacency					
visibility (yes = 1, no = 0)		.13 (.22)	.14 (.21)	.10 (.23)	.22 (.21)
easy updates (yes = 1, no = 0)		-.41 (.38)	-.23 (.37)	-.25 (.38)	-.07 (.35)
Connectivity					
log distance sterile corridor (feet)		-.07 (.16)	-.14 (.15)	-.15 (.16)	-.09 (.15)
centrality (yes = 1, no = 0)		.34 (.19)	.31 (.17)	.31 (.18)	.19 (.17)
Access area					
traffic free schedule (yes = 1, no = 0)		-.17* (.07)	-.19** (.06)	-.19** (.06)	-.15* (.06)
gathering schedule (5 point Likert)		-.04 (.06)	-.07 (.06)	-.08 (.06)	-.05 (.06)
barrier free schedule (yes = 1, no = 0)		-.18 (.16)	-.12 (.16)	-.13 (.16)	-.03 (.15)
sitting around schedule board (5 point Likert)		.11 (.06)	.12* (.06)	.12* (.06)	.08 (.06)
Information environment					
Communication practice			-.10 (.13)	-.09 (.13)	-.05 (.12)
face-to-face hotspots (5 point Likert)					
face-to-face elsewhere (5 point Likert)			.16* (.10)	.17 (.11)	.19* (.10)
media (5 point Likert)			.11 (.11)	.09 (.12)	.06 (.11)
Schedule board					
# information displayed			-.08* (.03)	-.09* (.04)	-.07* (.03)
posters around schedule board (yes = 1, no = 0)			-.09 (.15)	-.09 (.16)	.01 (.15)
log schedule board surface (inches)			.48* (.22)	.46* (.23)	.41* (.21)
electronic display (yes = 1, no = 0)			-.37 (.21)	-.35 (.22)	-.26 (.20)
Information sharing					
congregating (5 point Likert)				.07 (.18)	.10 (.16)
updating (5 point Likert)				.03 (.09)	.05 (.08)
Coordination outcomes					
coordination speed (5 point Likert)					-.40** (.12)
R^2 (R^2 adjusted)	.03 (.01)	.31 (.19)	.53 (.36)	.53 (.34)	.61 (.45)
F Full Model	1.13	2.51*	3.21****	2.80***	3.66****
Degrees of Freedom	2, 64	10, 56	17, 49	19, 47	20, 46
R^2 Change	.03	.28	.22	.004	.08
F change	1.13	2.79**	3.22**	.19	9.91***
DF Change	2, 64	8, 56	7, 49	2, 47	1, 46

[1] See Table 5-4 for variable definitions.

An electronic display board is typically a large plasma screen used to display the surgical suite schedule and sometimes personnel schedules for coordinating the daily operations and management in the surgical suite (Figure 5-2). As I will describe in more detail below, these electronic schedule boards have properties (e.g., multiple boards can display the same information) that may alter information exchange among personnel using the board. For example, the presence of multiple displays with the identical information may reduce congregating among workers (because each has stopped at a separate display) and thus reduce coordination opportunities. What, if any, changes are necessary to the architecture to make it applicable to electronic schedule boards?

Figure 5-2. Electronic display in a surgical suite.

At the outset, using the survey data to examine differences between the hospitals with and without electronic schedule boards is prone to error because respondents reported about their experience with one schedule board. Since half of the hospitals with electronic boards had manual boards as well, I do not know which board these respondents were referring to in the survey. If I then examine only the data from respondents in hospitals with electronic boards, the sample becomes too small. Therefore, the following discussion is only exploratory.

I expected to find differences in workplace, architecture, information, and information sharing in surgical suites with electronic displays.

- *Workplace.* Electronic displays, can maintain the information on multiple displays synchronized throughout spaces in a surgical suite and hospital. Electronic displays will be found in surgical suites of larger hospitals (i.e., with more beds) because they are more cost effective in larger hospitals.
- *Architecture.* Information technology allows people to communicate over distances, and communicate across local barriers (i.e., walls, doors, floors, etc.). I anticipated differences in architectural features in surgical suites with manual boards compared to those with electronic displays. Updating manual schedule boards is labor intensive. Thus, manual schedule boards are limited to central locations where staff is available to keep them up-to-date. Instead, for electronic displays, extra people to update are unnecessary for each additional display.
- *Information.* Surgical suites with electronic displays will have more displays throughout the hospital. Electronic displays are smaller than manual schedule boards. Thus, electronic display will provide less information per surgery.
- *Information sharing.* The greater number of schedule boards in units with electronic displays will be associated with less congregating around electronic displays. Unlike manual boards, people can update electronic displays from multiple locations in a surgical suite. I expect staff to congregate to find information on a display, but not necessarily to update it.
- *Coordination outcomes.* Networked electronic displays allow updates to travel instantly. Thus, one might expect faster coordination speed in surgical suites with electronic displays. However, electronic displays, like manual boards, require people to make updates. In previous field studies, I noticed slower coordination speed that when decision makers delegated updating activity. Conversely, decision makers that update the schedule board achieve faster coordination speeds. Thus, whether electronic boards increase coordination speed may depend on who does the updating.

Hospital Environment I show surgical suites with manual boards only, with electronic boards only, and with both in Table 5-15. The main difference seems to be that surgical suites with only manual boards are smaller hospitals. One notable exception pertains to surgical services per room, which instead is lowest for units with only electronic displays. This may reflect surgical suite specialization. Surgical suites with electronic displays, which tend to be in larger hospitals, may have surgical suites specialized to a single surgical specialty (and thus lower scores in services per room). The number of people in charge (i.e., charge nurse and charge anesthesiologist) was similar regardless of type of display. The same was true for the number of staff working at the control desk.

Table 5-15. Surgical suites with manual boards only, electronic schedule board only, and with both manual boards and electronic displays.[1]

	Manual Board(s) Only (N = 74)	Electronic Board(s) Only (N = 11)	Manual and Electronic Boards (N = 10)
# Operating rooms	6,71, SD 4.22	17.45, SD 6.85	11.40, SD 5.31
# Hospital beds	176.61, SD 127.93	438.18, SD 170.63	291.78, SD 159.16
# Surgical services present	8.01, SD 2.89	11.55, SD 1.97	9.10, SD 2.28
# Surgical services per room	1.92, SD 1.09	.83, SD .38	3.79, SD .60
# Surgeries per room	3.79, SD 1.33	3.15, SD 1.26	3.79, SD 59

[1] See Table 5-4 for variable definitions.

In all my subsequent analyses, I compared hospitals with only manual schedule boards and electronic schedule boards only. As mentioned previously, I did not consider the 10 hospitals with both electronic and manual schedule boards because the respondents only described one schedule board, but did not specify which one they were describing.

Architecture. Surprisingly, there were few differences in the mean values of architecture environment variables (Table 5-16). One exception is the distance between the schedule board and the control desk, which was greater for surgical suites with only manual boards.

I ran a linear regression with the log 10 distance between schedule board and control desk as the outcome variable (I applied a log transformation because it was skewed). In the first block, I inserted two control variables: log 10 number of hospital beds to control for hospital size, and surgeries per room to control for scheduling load: In the second block, I added a binary dummy variable for electronic displays only.

The control variables were poor predictors for the distance between schedule board and control desk (R^2= .06, F Change [2, 77] = 2.73, p. =.07). Likewise adding the dummy variable for electronic displays did not predict the distance between schedule board and control desk (R^2= .06, F Change [1, 76] = .85, p= .36). Again, this may be due to small sample size.

Table 5-16. Mean values for architecture environment variables by type of schedule board present (i.e., manual board only, electronic board only, and both manual and electronic display).

	Manual Board(s) Only (N = 74)	Electronic Board(s) Only (N = 11)	Manual and Electronic Boards (N = 10)
Visibility (5 point Likert)	4.18, SD 1.37	4.09, SD 1.58	4.11, SD 1.53
Audible (5 point Likert)	4.14, SD 1.34	3.60, SD 1.65	3.40, SD 1.56
Distance board control desk (feet)	12.74, SD 14.94	4.89, SD 4.88	11.25, SD 9.91
Schedule board central (1 = yes, 0 = no)	.79, SD .65	.90, SD .30	1.00, SD .00
Barrier free (1 = yes, 0 = no)	.40, SD .49	.09, SD .30	.30, SD .48
Distance can read schedule board (5 point Likert)	3.39, SD 1.25	2.64, SD 1.21	3.10., SD 1.45
People can gather around schedule (5 point Likert)	3.12, SD 1.19	3.45, SD 1.13	3.50, SD 1.35
People sit around schedule board (5 point Likert)	3.20, SD 1.29	3.63, SD 1.43	4.10, SD 1.45
Eat and drink around schedule board (5 point Likert)	1.92, SD .92	1.90. SD 1.30	2.35, SD 1.44

[1] **See Table 5-4 for variable definitions.**

Information. I next investigate whether there are differences in the information setting based on the type of schedule board.. The amount of information on the schedule board was similar for manual schedule boards and electronic schedule boards. There was significantly more information posted around manual schedule boards compared to electronic schedule boards. Electronic displays were located significantly higher from the ground than manual boards. Participants from surgical suites with electronic schedule boards reported more displays. Discussion of schedule changes in information hotspots (i.e., schedule board and control desk) was similar for all kids of schedule boards. Discussion of schedule changes elsewhere in surgical suites was similar for all kinds of schedule board. Likewise, the use of communication media was similar for all kinds of schedule boards. It could be that the limited results hinge on the few surgical suites in the sample with electronic displays (i.e., N=11). Table 5-17 shows the basic statistics for the information related variables.

Table 5-17. Information by type of display. [1]

	Manual Board(s) Only (N = 74)	Electronic Board(s) Only (N = 11)	Manual and Electronic Boards (N = 10)
Amount of information displayed #	8.62, SD 2.14	9.27, SD 2.53	8.60, SD 1.78
Information around display (1 = yes, 0 = no)	.72, SD .45	.18, SD .40	.65, SD 48
Distance display from floor (inches)	39.98, SD 14.26	55.50, SD 10.99	41.05, SD 14.61
Number of displays	1.48, SD 1.57	6.45, SD 7.55	3.00, SD 1.15
Face-to-face hotspots (5 point Likert)	3.61, SD .65	4.09, SD .44	4.00, SD .47
Face-to-face elsewhere (5 point Likert)	3.18, SD .76	2.76, SD .82	2.93, SD .87
Media (5 point Likert)	2.77, SD .71	3.15, SD 1.10	2.82, SD .78

[1] **See Table 5-4 for complete variable definitions.**

To test for statistical significance, I used the linear regression described previously (5.3.5) to predict information posted around the schedule board. In the first model, I added two control variables (i.e., number of hospital beds and surgeries per room). In the second model, I added electronic display as an independent variable as a last variable.

The control variables were poor predictors for information posted around the schedule board (R^2= .007, F Change [2, 95] = .32, p. =.73). However, adding the dummy variable for electronic displays significantly improved prediction of information around the schedule board (R^2= .12, F Change [1, 94] = 12.09, p= .001). Having an electronic display was significantly associated with less information posted around the schedule board (t=-3.48, p = .001). The difference in height from the floor may explain such difference in information posted around the schedule board. People can easily post information around the manual schedule boards because they are within reach (i.e., three and half feet from the ground). Electronic schedule boards instead are harder to reach because they are close to 5 feet from the ground. Manual schedule boards are larger than electronic boards and thus provide more space to host information.

Surgical suites that used only manual schedule boards had fewer schedule boards compared to surgical suites that used only electronic displays (1.48 displays vs. 6.45 displays). To test for statistical significance, I used the same procedure as above to predict the number of schedule board displays present.

The control variables were discrete predictors for the number of schedule boards displays (R^2= .08, F Change [2, 106] = 4.68, p. =.01). Adding the dummy variable for electronic displays significantly improved prediction of number of schedule boards present (R^2= .16, F Change [1,105] = 9.13, p= .003). Two variables greatly improved predication of number of displays present: the dummy variable for electronic displays was significantly associated with more schedule displays present (t=3.02, p = .003) and a greater the number of beds in the surgical suites (log transformed) was associated with more displays present (t=1.94, p = .05).

Information sharing and coordination outcomes. I next investigated whether there were differences in updating activity, coordination speed, and coordination stress across surgical suites with manual schedule boards versus electronic schedule boards. Table 5-18 provides the basic statistics for congregating, updating, coordination speed, and coordination stress.

Table 5-18. Information sharing and coordination outcomes by type of schedule board. [1]

	Manual Board(s) Only (n = 74)	**Electronic Board(s) Only (n = 11)**	**Manual and Electronic Boards (n = 10)**
Congregating (5 point Likert)	3.44, SD .73	3.44, SD 1.07	3.57 SD .51
Updating (5 point Likert)	2.51, SD .87	2.77, SD 1.44	2.20, SD .58
Coordination speed (5 point Likert)	3.89, SD .99	4.73, SD .65	4.01, SD .57
Coordination stress (5 point Likert)	2.75, SD 1.57	2.20, SD .68	2.68, SD .58

[1] **See Table 5-4 for complete variable definitions.**

I used the linear regression described previously (5.3.5). I added electronic display as an independent variable as a last variable to the regression models to predict congregating, updating, coordination speed, and coordination stress. I used the same blocks as described previously to test the hypotheses above. I found no significant differences based on type of schedule board. The lack of differences may result from the small number of surgical suites with electronic displays in the sample.

Almost half of the surgical suites with electronic displays reported using whiteboards as well. Further work is necessary to determine why electronic displays and whiteboards co-exist in some surgical suites. Are the whiteboards displaying information that is not included in the electronic displays? Are the whiteboards and electronic displays side-by-side or used in separate locations?

5.4 Results Summary

Features of the architecture and information matter for information sharing and coordination outcomes. In the section that follows, first, I summarize the main findings according to the model in Figure 5-3.

Figure 5-3 outlines significant positive and negative relationships among the variables tested in my model. Larger hospitals, that is, ones with more hospital beds, were associated with less congregating around the schedule board to get information. Architecture factors as a whole predicted congregating, as did information. These factors, taken as a whole, did not predict updating, which I interpret as due to the mandatory nature of updating. Architecture factors also predicted coordination speed and coordination stress.

As discussed in the next chapter, variations in the number of people skipping particular questions (e.g., more skipped questions asking them to measure the size of the board) suggests that measurement error varied across the architecture measures. Thus, it is hard to distinguish the importance of one facet of the architecture from another. To be conservative, I infer that features of architecture, together, along with information artifacts that brought people in front of the board, were associated with congregating to share information about the schedule.

Ignoring likely measurement error, two architecture factors, having a traffic-free area around the schedule board and having visibility between the schedule board and control desk, had significant impacts on information sharing and outcomes. Visibility between the schedule board and control desk was associated with more frequent congregating around schedule board and faster coordination speeds. Traffic-free areas, in which people could stand and observe the board, were associated with lower stress. In addition, three aspects of the information were important for schedule coordination. When the board was easier to update, people learned about schedule changes faster than when the schedule board was more difficult to update. When more types of information were displayed on the board (e.g., patient, condition, surgeon assigned, etc.), people experienced less stress, but when the surface of the schedule board itself was larger (without concomitant increases in information), stress increased. Finally, aspects of the work environment, included in the model as control variables, were also associated with information sharing and outcomes.

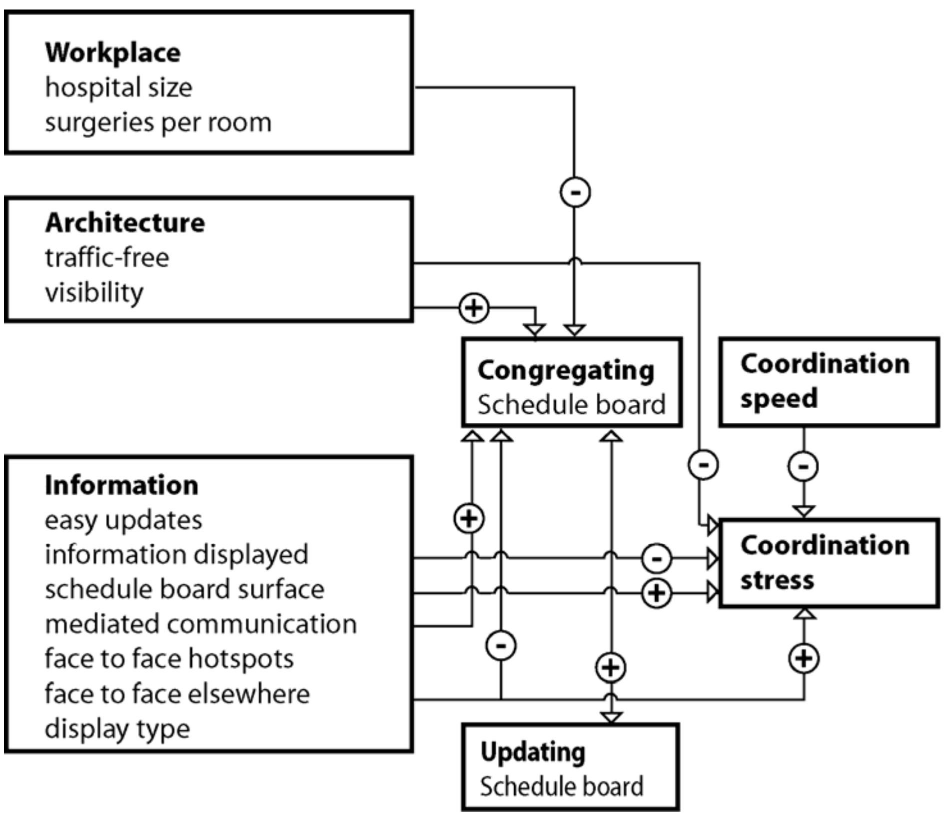

Figure 5-3. Diagram of the schedule board data. The lines represent significant linkages from the hierarchical regression analysis; the numbers are the unstandardized beta coefficients; levels of significance are expressed as * p<.05 and ** p<.01.

Due to the small number of hospitals reporting use of electronic schedule boards only, and the fact that these were generally large hospitals with specialized services, I was not able to discern the effects of electronic boards on coordination. However, the findings do suggest that in hospitals with electronic boards, information about the schedule is dispersed and more people have this information at hand. This situation could have positive and negative effects, as mentioned above. One positive effect could be that people get updates without having to look for them. A negative effect is that the scheduling information is less usable, and that scheduling becomes more out of their control because they have not discussed the changes. It is also possible that delegating schedule updates into the information system results in slower coordination speed.

5.5 *Discussion*

Workplace. Larger hospitals have bigger buildings, more beds, more operating rooms, and thus more staff. I found that fewer different types of staff congregated together in hospitals with more beds. One explanation may be that in larger hospitals, staff are more inclined to interact with those like themselves.[17] Another explanation is that in larger hospitals, more foot traffic may interfere with congregating around the schedule board. Crowding and traffic around the schedule board in turn may discourage congregating. The data showed that schedule boards with more gathering space around them—allowing staff to read the schedule board comfortably —tended to be associated with more frequent congregating across roles.

Architecture. Visibility of information and people, and communication among people, were the most important factors associated with congregating around the schedule board. Congregating and updating seem to be associated, perhaps because while someone updates the schedule, others are likely to stop by to see the change. Likewise, in surgical suites where schedule is constantly up to date, staff may check the schedule board for schedule changes. Decision makers must agree before the schedule board updates occur.

[17] For instance, there usually is one charge nurse and one charge anesthesiologist in a surgical suite. However, the number of operating rooms determines other roles. For instance, usually there is one circulating nurse, and one scrub nurse, per operating room. As the operating rooms increase, the total number of staff in the surgical suite increases; however, the total number of roles is independent of the number of rooms.

Information. When staff relied heavily on mediated communication such as cell phones and pagers, they congregated more frequently around the schedule board, whereas when staff relied heavily on face-to-face communication in hotspots, they congregated less frequently. One explanation is that greater schedule uncertainty is associated with greater use of mediated communication. For instance, in some units frequent changes in the schedule would require much congregating negotiate schedule changes. Subsequently, there would be much mediated communication to inform all of the schedule changes. On one hand, key decision makers congregated more to discuss such schedule changes. On the other hand, staffs communicate schedule changes throughout the surgical suite and ancillary units affected by the schedule changes with a variety of mediated communication channels.

Congregating. Somewhat surprisingly, no aspects of the schedule board significantly predicted congregating in this study. One explanation may be that, different staff roles may congregate around the schedule board for many reasons. In addition, there are other ways for the staff to learn about schedule changes (i.e., ask the control desk staff, make a phone call, ask colleagues, etc). Similarly, with an out-of-date schedule board congregating is unlikely to be associated with the schedule board features.

Updating. Contrary to my expectations, no environmental factors were significantly associated with updating activity. One explanation is that schedule board updating follows workplace norms independent of the environmental factors. As such, the effects of environmental factors may be noticeable in the coordination outcomes (coordination speed and coordination stress).

Updating activity increased with congregating (and vice versa). One might expect that in surgical suites with more surgeries per room the staff is more likely to monitor the schedule board to learn about schedule changes and remove finished cases in between surgeries. However, I did not find evidence to suggest linkages between the number of surgeries per room to congregating and updating. One explanation could be that in some surgical suites updates to the schedule board are mandated at particular times of day regardless of the number of surgeries per room (i.e., before the start of a shift, mid-morning, before lunch, mid-afternoon, and before the end of the shift).

Another explanation may be that uncertainty about the surgery schedule may predict congregating around the schedule board, and updating the schedule board. For example, critical patients cannot undergo surgery if they become unstable, and another patient takes the scheduled time slot. In the case of last minute schedule changes, to ensure patient safety and efficient use of resources surgery staff needs to: (a) prepare the correct patient for surgery, (b) draw the anesthesia drugs for the patient, (c) prepare the surgical tools accordingly, and (d) set up the operating room for the new procedure. In summary, uncertainty in surgical schedules may encourage staff to monitor the schedule board for updates more frequently. It is possible that people sat at the schedule board to wait for information, and in units where there was more uncertainty about the schedule. If so, then the association would be negative. One would not want to remove the benches, and induce people to go elsewhere because they might miss important updates to the schedule. I saw this situation arise in a trauma unit, in my previous study.

Coordination speed. Coordination speed is a complicated situation. Aspects of the architecture and information may combine to change coordination speed. A model that used only architecture to predict coordination speed showed that people coordinated more rapidly with two conditions: (a) when the schedule board and control desk were reciprocally visible, and (b) when the schedule board was easier to update. Adding the information variables weakened the predictive power of visibility and ease of updates to trends, while the frequency of people sitting around the schedule board approached significance.

Visibility describes the visual relationship between the schedule board and control desk. Regarding congregating, on one hand, high visibility scores may mean that the schedule board is in a more interesting location where multiple teams congregate around the schedule board and control desk (i.e., surgical suite nursing, anesthesia, surgery, and so forth). As such, inter-group congregating scores are higher. On the other hand, less visibility between the schedule board and control desk, may mean that the schedule board is located in an isolated hallway and the groups that congregate there cannot see the groups that congregate at the control desk. As such, there is less congregating between groups at the schedule board.

When staff coordinated more rapidly, they reported feeling less stress. One explanation is that, increased visibility can increase coordination speed directly. The control desk is located visually to control the entrance to the sterile corridor. Visibility between the schedule board and control desk may affect coordination speed directly in three ways. (a) Greater visibility may make it easier to see who enters and exits the sterile corridor. (b) Those congregating and passing through a space have more coordination opportunities with greater visibility and (c) those that are congregating may have a better sense of what is happening in the surgical suite (i.e., situation awareness). As such, visibility may offer opportunities for faster coordination. In surgical suites where people cannot easily see each other, the alternative is to page someone, wait for a call back, or call someone and find the line busy.

The presence of traffic-free areas around the schedule board may directly facilitate information exchange processes, and the creation of a common information spaces for groups. The presence of traffic-free areas around the control board reduced stress both directly and indirectly, by increasing congregating. The presence of traffic-free areas around the schedule board may mean that the schedule board is a good place to stop because there will not be interference from people passing through. Furthermore, the lack of interference may support staff gathering around a shared representation of the schedule during negotiations.

Coordination stress. Coordination stress decreased when the schedule board contained information that is more complete for each surgery listed (i.e., type of surgery, surgeon, etc). However, coordination stress was greater with larger schedule boards. One explanation is that larger schedule boards are in hospitals with more beds and operating rooms. To test if larger displays coincide with larger hospitals, I ran a linear regression testing the effects surgeries per room, number of operating rooms, and number of hospital beds (to unskew variables I applied log transformations) on schedule board surface size. Sure enough, the number of surgeries per room, hospital beds, and operating rooms predict the surface of the schedule board ($R^2 = .22$, F Change $[3,77] = 7.03$, $p. < .001$). The more surgeries per room, the greater the size of the schedule board ($t = 2.42$. $p. < .05$). The greater the number of operating rooms, the larger the schedule board ($t = 3.80$,

p. < .001). The greater the number of hospital beds, the smaller the size of the schedule board ($t = -2.21$, $p < .05$).

The size of the schedule board is associated with the type of schedule board. Manual schedule boards are larger than electronic displays. However, I did not find any statistical difference for coordination stress based on type of schedule board used (Chapter 5). Greater sized manual schedule displays are in surgical suites with more surgeries per room, more operating rooms, and fewer hospital beds. Electronic displays instead are smaller, and are in hospitals with fewer surgeries per room, more operating rooms, and more hospital beds.

When surgical suite staff discussed schedule changes face-to-face around the surgical suite (i.e., in hallways, break-rooms, cafeterias, and other locations) they reported a greater level of coordination stress. One explanation is that greater coordination stress results from running around the surgical suite to find out about schedule changes. Instead, coordination stress is lower in surgical suites where people find out about schedule changes in central information hotspots, such as the schedule board and control desk.

More spacious areas around the schedule board—ones that allow key coordinators to gather comfortably—were associated with lower coordination stress. I subtracted the number of people with charge roles from the number of people who could comfortably gather around the schedule board. Negative numbers indicate that there were more people with coordination roles than space to gather in front of the schedule board. Zero means that there is enough room. Positive numbers mean that there is room for more people to gather. I added the key coordinator gathering measure to a model predicting coordination stress. The model trended towards better prediction of coordination stress ($R^2 = .63$, F Change $[1,46] = 3.22$, $p < .08$). This provides partial support for creating access areas large enough to allow decision makers to congregate. In the final model, traffic-free areas around the schedule board reduced coordination stress ($t=-.13$, $p<.05$). Face-to-face coordination throughout the surgical suite increased coordination stress ($t=.22$, $p<.05$). The more complete the information displayed on the schedule board the lower the coordination stress ($t=-.08$, $p<.05$). The greater the coordination speed the lower the coordination stress ($t=-.43$, $p=.001$). Finally, surgical suites with more space to accommodate the people with coordination roles around the schedule board, trended towards lower coordination stress ($t=-.19$, $p<.08$).

An unexpected set of findings concern the relationship between the information sharing I measured and the coordination of outcome measures (how quickly people learned of changes, how stressful these changes were). I did not find a direct link between schedule board updating and coordination outcomes. One explanation may be that in surgical suites, there is a certain redundancy of communication media. For example, staff with key coordination roles, may carry a pager, a personal phone, a role-based phone, and a handheld computer. As such, there are multiple channels for information transmission. Redundancy in surgical suites is necessary because lives are at stake, and there is financial pressure to use resources efficiently. Different channels of communication have different speeds. As such, to explain the link between updating activity in general and coordination speed in surgical suites, one must measure all communication channels used to transmit updates.

Another explanation regards the information sharing analyzed. I focused on the linkage between schedule board updating activity and coordination speed. I now speculate that updating the schedule board is one form of information sharing, but not the only information sharing activity that affects coordination speed. For example, updating the schedule board is one way to represent agreed upon schedule changes publically. However, before the schedule board can be updated, private agreement between the key decision makers is necessary (i.e., the charge nurse, the charge anesthesiologist, and the surgeon). Furthermore, before a private agreement between groups is possible, a private agreement within each team must be in place.

In surgical suites, much coordination occurs—both between groups and within groups—before the schedule board displays updated information. The key decision makers (i.e., charge nurse, charge anesthesiologist, and surgeons) represent different groups, and may need to negotiate schedule changes within their respective groups. For example, the charge nurse must ensure that the surgical equipment and operating room staff is available, and so forth. Likewise, the charge anesthesiologist may negotiate the proposed schedule change with other anesthesiologists and the anesthesia team staff. It follows that, coordination speed depends on the communication channels used to coordinate both: (a) within groups, and (b) between groups. As such, the information sharing between and within the various groups may be better predictors of coordination speed than schedule board updating.

The next chapter discusses the findings and speculations in light of the field studies, and the implications for design.

Chapter 6: Contributions to Design, HCI, and Behavioral Research

The surgical suites of hospitals present extraordinary challenges to coordination among groups of people. In this dissertation, I studied how aspects of hospital architecture, information, and workplace were associated with information sharing and coordination outcomes in the complex work environment of hospital surgical suites. In the first part of my work, I conducted two field studies in four hospital surgical suites (Chapters 2 and 3). In the field studies, I observed linkages among architectural features, information artifacts, and information sharing behavior around schedule boards and control desks. Based on prior research and my field study data, I developed the concept of an *information hotspot* – a place where three conditions coincide: people congregate to receive and provide information; public displays offer up-to-date information; and coordination workers are present to answer questions, resolve conflicts, and keep information up-to-date.

The information hotspot concept guided my design explorations. In chapter four, I developed four conceptual tools for surgical suite design: design principles for the placement of schedule boards and control desks; design guidelines for the location of surgical suite displays and control desks; an evaluation tool for surgical suites; and a three-tiered design intervention strategy ranging in implementation effort.

In the third part of my work, I sent a survey to surgical suite directors nationwide. I further investigated the linkages among architecture, information, workplace factors, and coordination outcomes. Unfortunately, close to 30% of respondents skipped some of the questions measuring surgical suite architecture and information. When using regression analysis, incomplete data increases the likelihood of measurement error. Given this limitation, I determined that features of architecture, together, along with information artifacts that brought people in front of the board, were associated statistically with staff members congregating to share information about the schedule.

Two architecture factors—having traffic free areas around the schedule board and providing visibility between the schedule board and control desk—had statistically significant relationships with information sharing and outcomes. Visibility between the schedule board and control desk was associated with more frequent congregating around the schedule board and faster coordination speeds. Traffic-free areas, in which people could stand and observe the board, were associated with lower stress. In addition, three aspects of the information display were important for schedule coordination. When the schedule board was easier to update, people learned about schedule changes faster than when the board was more difficult to update. When more types of information were displayed on the board (e.g., patient, condition, surgeon assigned, etc.), people experienced less stress, but when the surface of the schedule board itself was larger (without concomitant increases in information), stress increased. Finally, aspects of the work environment, included in the model as control variables, were also associated with information sharing and outcomes.

Due to the small number of surgical suite directors reporting that their hospital used electronic boards rather than traditional manual whiteboards for displaying the surgery schedule, and the fact that their surgical suites were generally larger, with more specialized services, than other hospitals, I was not able to discern the effects of electronic boards on coordination. Electronic boards make distributing scheduling information easier; updates in one location (such as the control desk) are visible instantly on other boards. I speculate that in hospitals with electronic boards, schedule information can be decentralized and/or dispersed widely, which in turn means that more people have this information at hand. As I note in chapter five, this situation could have positive and negative effects. One positive effect could be that people get updates without having to look for them. A negative effect could be that scheduling updates are less usable by staff members who are unaware of the wider context of the schedule change and what it means for how they coordinate their activities. It is also possible that delegating to someone the task of updating the schedule via a computer interface results in slower updates and less consensus on these changes.

In summary, the main contribution of this dissertation is the idea that the location of large schedule displays, the characteristics of the hospital’s architecture around such displays, and the information available on and around the displays are associated with coordination processes and outcomes. More precisely, for the task of coordinating schedule changes in surgical suites, three factors are critical: a visual relationship between the schedule board and control desk in the surgical suite, traffic-free areas around the schedule board, and complete, up-to-date schedule board information. These factors lead to greater congregating and faster coordination speed as predicted by the concept of information hotspots. Lower coordination stress resulted from faster coordination speeds.

In the sections that follow, I discuss the contributions of my work, consider the limitations of the research, and outline future research.

6.1 Contributions

This dissertation contributes in three areas: design, HCI, and behavioral research.

6.1.1 Design

From a design perspective, this dissertation provides two types of contributions: conceptual design tools and design methodology to generalize implications for design from fieldwork. First, I developed a range of conceptual design tools for the placement of large displays, control desks, and the architecture of surgical suites. Second, I demonstrated a design methodology to generalize implications for design from a small sample fieldwork to a national sample survey.

Design tools for surgical suites. I used an iterative process to develop the surgical suite design tools. I conducted two rounds of field studies in four surgical suites. Analysis from the first field study informed the second. The concept of information hotspots, the design principles, and the design guidelines came from careful analysis of field data from both field studies. Next, I explored the design space of the four surgical suites. I developed design alternatives for each site (Chapter 4). I proposed design solutions according to a three level strategy based on implementation effort (low, medium, and high effort). To evaluate the design solutions resulting from my design exploration and compare them, I transformed the design principles into an evaluation checklist.

Figure 6-1 represents the iterative processes I used. I began with two field studies that lead to the information hotspot concept. The information hotspot concept and the data from the field studies lead to the design related work. The information hotspot concept and the design principles informed the national survey. With the survey, I found some support for the ideas contained in the design principles, and guidelines. Next, I revise the design principles, design guidelines, and evaluation checklist according to the survey results.

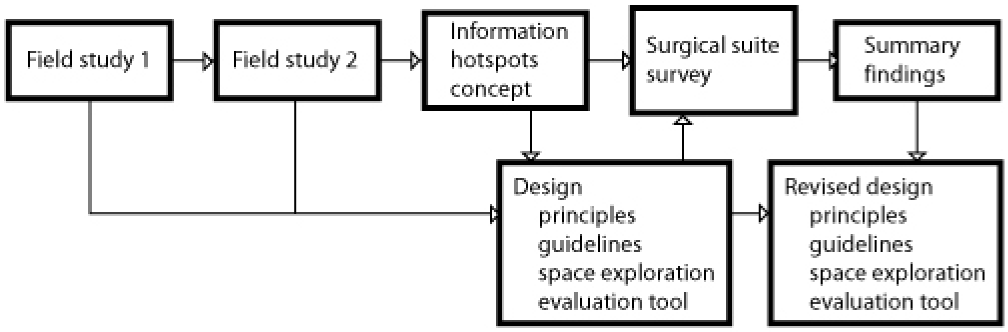

Figure 6-1. Idealized diagram of the iterative research cycles.

Revised design principles and design guidelines. As described in Chapter Four, I developed the design principles from fieldwork, by studying positive and negative coordination events in four particular sites. In chapter five, I asked surgical suite directors about how factors regarding architecture and information around schedule boards were associated with information exchange and schedule coordination outcomes. Next, I discuss the implications of such survey findings for the design principles and design guidelines.

I decided to weigh the design principles to reflect the survey findings. I wanted to determine if the survey findings changed the evaluation scores of the surgical suites studied (Chapter 4). I placed the design principles into two tiers based on the evidence available (i.e., field study evidence, survey evidence, or both).

Table 6-1 shows in the first column the design guidelines, in the second column the respective design principles, and in the last column the evidence source. The supported design principles are in bold. I edited the design guidelines to reflect the survey findings. Design principles supported by field data alone are in roman text. In the next section, I use the weighted design principles to evaluate the four surgical suites studied in field studies.

Table 6-1. Survey support for the design guidelines and design principles developed from field studies.

	Revised Guidelines		Design principles	Survey support
1	**Place the schedule board and control desk so that they are mutually visible** and their access areas overlap, **so that staff from the control desk can easily update the whiteboard.**	**3**	**Increase intergroup visibility around shared information artifacts.**	**Yes**
		5	Provide overlapping information access areas for information artifacts used together.	Partial
		14	**Reduce effort necessary to update information displays.**	**Yes**
2	**Locate the schedule board and control desk-separate from conflicting activities.**	1	Locate control desk and schedule board in a highly connected area.	Perhaps
		6	Locate surgical suite schedule board and control desk in a space leading to the sterile corridor.	Perhaps
		15	**Separate information access areas from conflicting activities.**	**Yes**
3	**Provide pause locations for people to access the schedule board and control desk that are out of the way of traffic, allow monitoring of bystanders, and make corridors wide enough for traffic to pass.**	**2**	**Provide pause locations that allow monitoring of bystanders.**	**Yes**
		7	**Put workers in pause locations out of the way of traffic.**	**Yes**
		9	**Size corridors to keep pause locations clear of traffic.**	**Yes**
4	**Size information access areas so decision makers can congregate.**	**13**	**Size information access areas so decision makers can congregate.**	**Yes**
5	Encourage compatible multiple uses of spaces around information displays.	8	Encourage compatible multiple uses of spaces around information displays.	Perhaps
6	**Locate the schedule board where patient privacy legislation allows displaying information.**	**10**	**Locate control desk and schedule board where patient privacy legislation allow displaying information.**	**Yes**
7	Orient furniture to maximize information display exposure.	4	Arrange furniture and furnishings to maximize information access areas.	Perhaps
		12	Orient furniture to maximize display exposure.	Perhaps
8	**Provide enough surfaces to display information.**	**11**	**Provide enough surfaces to display public information.**	**Yes**

Evaluation checklist. I weighted the evaluation checklist according to the support that each design guideline received. I weighted design principles that were supported by the survey and field data twice as much as design principles supported only by field data. Although this weighting scheme is simplistic, it has heuristic value.

Table 6-2 shows the design evaluation checklist based on the design principles and a weighed score for each field study surgical suite. The weighted scores are as follows: 0 = condition not met; 1 = field condition met; 2 = both field and survey conditions met. Interestingly, weighting the design principles gave the same ordering of surgical suites as with the unweighted evaluation list (Chapter 4). Likewise, the ordering of the surgical suites remained unchanged when using two different subsets: (a) using only the design principles supported by the survey data or (b) using only the design principles supported by the field data. I provide this as an illustration of updating the design principles. Future work should test the design principles and design evaluation tool on surgical suites that were not part of the field study or the national survey.

Table 6-2. Comparing the four locations studied side by side with the 15 principles. (0 = no; 1 = supported by field study only; 2= supported by both field and survey).

	Pennsylvania Study		**Maryland Study**	
Information Hotspot Principle	**XL**	**Medium**	**Large**	**Small**
1. Locate control desk and schedule board in a highly connected area.	0	1	1	1
2. Provide pause locations that allow monitoring of bystanders.	0	2	0	2
3. Increase intergroup visibility around shared information artifacts.	0	2	2	2
4. Arrange furniture and furnishings to maximize information access areas.	0	1	0	1
5. Provide overlapping information access areas for information artifacts used together.	0	2	0	2
6. Locate schedule board and control desk in a space leading to the sterile corridor.	0	1	0	1
7. Put workers in pause locations out of the way of traffic.	2	2	0	2
8. Encourage compatible multiple uses around information displays.	0	1	0	1
9. Size corridors to keep pause locations clear of traffic.	0	2	0	2
10. Locate control desk and schedule board where patient privacy legislation allow displaying information.	0	2	0	2
11. Provide enough surfaces to display public information.	1	0	0	1
12. Orient furniture to maximize display exposure.	1	0	0	1
13. Size information access areas so decision makers can congregate.	0	2	2	2
14. Reduce effort necessary to update information displays.	2	0	0	2
15. Separate information access areas from conflicting activities.	0	2	0	2
Partially supported items (1 point)	2	4	1	6
Fully supported items (2 points)	4	16	4	18
Total points	**6**	**20**	**5**	**24**

Design methodology contribution. Fieldwork informs design decisions in many traditions (i.e., workplace studies, contextual inquiry, and activity theory). Typically, detailed fieldwork in one site, with one population, or organization may provide the system requirements that inform the design of a particular tool or service in that context. One limitation to such an approach is that knowledge generated from small sample field studies may have limited applicability to artifacts and services designed for the sites studied.

Work from the ethnographic tradition of workplace studies in HCI and CSCW, has informed system designers by describing the workplace, the work practice, and identifying user requirements, necessary to develop computer technology for particular work domains (e.g., Button, 2000). There are two aspects to ethnographic fieldwork often used in the workplace study tradition: a rich description of what happens in a site, and conceptual materials that describe how these data are theorized, understood and interpreted (e.g., Dourish, 2006). Researchers may provide “implications for design” to inform designers working on analogous design problems in similar settings (Rogers et al., 1995).

One of the design goals of contextual inquiry is to develop a customer-centered design process. In other words, the design goal is to enable a design team to design a particular work practice (Beyer & Holtzblatt, 1998). Activity theory in HCI can focus on the appropriateness of a certain tool for a particular work practice. Activity theory can focus on both the analysis and design activity of a particular work practice (i.e., considering the qualifications of workers, the work environment, the division of labor and so forth). Researchers can use the activity theory approach to study how the introduction of a particular artifact can change practice, and vice versa (e.g., Bertelsen & Bodker, 2003).

Researchers conducting fieldwork, and designers aiming to learn from fieldwork, have a conundrum. On one hand, it may seem reasonable to extrapolate from field studies of one site to the next. However, it is necessary to determine if such an extrapolation is in fact justified. On the other hand, some may ignore findings from fieldwork and miss the opportunity to build on prior research. This conundrum applies to the workplace study tradition, contextual inquiry, and activity theory tradition.

My dissertation demonstrates a way forward for researchers and designers because it differs from these traditions in three ways: research goals, design goals, and methodologically. First, I went into the field with the research goal of understanding the linkages between the architecture of the built environment, information artifacts and coordination processes and coordination outcomes.

Second, my design goal was to develop surgical suite design tools to inform the design of surgical suites. In other words, I did not intend to develop particular solutions for each surgical suite studied. As mentioned previously, I generated design tools (i.e., design principles, design guidelines, and a design evaluation tool) for the four sites studied (Chapter 4). I limited my design activity to exploring the design space with design sketches.[18]

Third, methodologically my approach differs from contextual inquiry, activity theory, and workplace studies. I studied four sites, and compared across these sites to understand what was common across all sites and what differed across these sites. The fieldwork allowed me first to develop the information hotspots concept and then the design tools. I developed a survey to test the information hotspot concept underlying the design tools applied beyond the four surgical suites studied. The survey allowed me to investigate the information hotspots concept in surgical suites nationwide (Chapter 5). In this section, I used the survey findings to revise the design principles and design guidelines.

In future work, the conceptual design tools described in this dissertation require integration into an evidence-based design research process. In the evidence-based design paradigm, four steps are necessary: (a) Evidence guides designers' design decisions; (b) Designers formulate hypotheses regarding the impact of design decisions on outcomes. (c) Designers collect data to test the hypotheses. (d) Evidence based designers publish the results of their work to increase the knowledge base of evidence-based design (Hamilton, 2003). Thus placing the information hotspot design tools in the evidence-based design paradigm can inform the design and assessment of new surgical suites (Hamilton, 2004).

6.1.2 HCI Research

My dissertation contributes to HCI the idea that the architecture of the built environment around large displays, the information displayed, and the workplace setting play a role in deployment success. More generally, to understand coordination work

[18] A design sketch is a starting point for a particular design solution, not a finished design solution.

around large displays in complex environments researchers must consider the physical setting and not just the information artifacts alone.

I introduced the term information hotspots—instead of coordination hotspots or centers of coordination (Suchman 1997)—to capture the relationship of three factors that converge to support coordination in a place: the architecture of the build environment, information artifacts, and people's behavior. The term *coordination hotspot* focuses too much attention on the activity of coordinating, and not enough on the architecture, and artifacts involved. The term *center of coordination* likewise describes a central place where coordination occurs, such as an airport control room or a railway control station. Information hotspots instead occur within centers of coordination. For example, in Large Surgical Suite in the Maryland field study, participants considered the "center of coordination" to include both the schedule board and control desk (Chapter 3). However, during my fieldwork it became clear that the information hotspot formed around the control desk and not the schedule board. As such, the information hotspot was a sub-area within a center of coordination.

In my field studies, I describe how surgical suite staff shape the architecture of the built environment surrounding schedule boards and control desks to support coordination processes. The nationwide survey of surgical suite directors provided further evidence of linkages between architecture, information, and workplace with how frequently people congregate, coordination speed, and coordination stress levels. As such, information artifacts and the architecture form a critical whole that is associated with coordination processes and coordination outcomes.

6.1.3 Behavioral Research

This dissertation contributes to behavioral research the idea that architecture, artifacts, and people's behavior converge to support coordination in information hotspots. The concept of information hotspots emerged from field studies in surgical suites. The nationwide survey of surgical suite directors provided a deeper understanding of the linkages between (a) architecture, information, and workplace and (b) information sharing and coordination events. In particular, in surgical suites, visibility between the schedule board, and control desk is associated with greater congregating activity, and faster coordination speeds. Greater coordination speed was associated with lower coordination stress. Coordination occurs at many levels in surgical suites. My work examined coordination at the surgical suite level, focusing on intergroup coordination.

6.2 Limitations and Future Directions

A number of factors limit this work. I describe the limitations in three sections: design, human-computer interaction, and behavioral science. For each limitation, I suggest future work. Figure 6-2 illustrates three future research areas to further the work presented in this dissertation. (a) Evidence-based design research activity can evaluate the design tools in the field. (b) A field study of surgical suites with electronic displays can clarify how coordination differs for the use of electronic vs. manual displays. (c) A survey study targeting surgical suites with electronic displays can test the generalizability of observations in field settings.

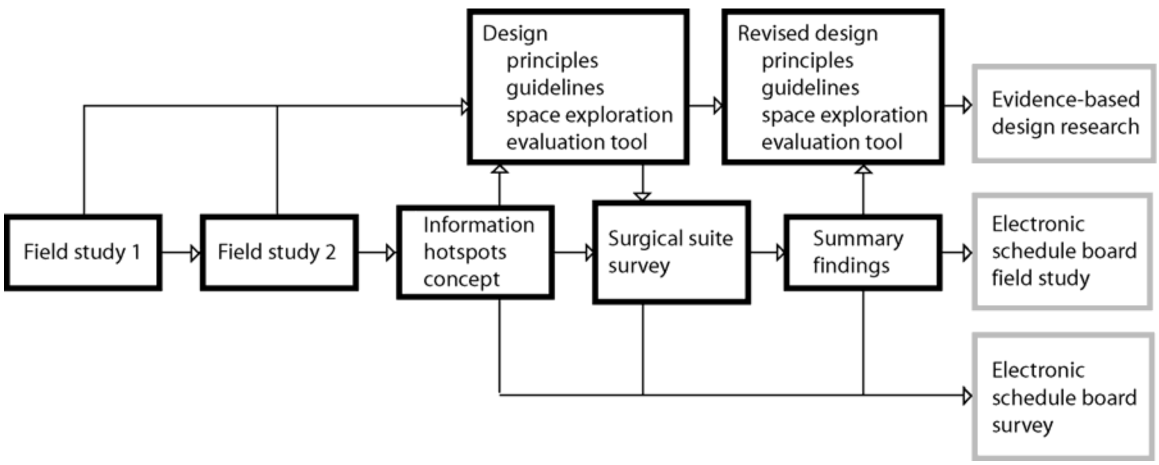

Figure 6-2. Idealized diagram of dissertation research cycles (black boxes) and future work discussed (grey boxes).

6.2.1 Design

From a design research perspective, my goal for both the field studies and national survey was to understand how the physical environment around large schedule boards supported coordination in the surgical suite. The goal of my dissertation was to make the research on large display placement in surgical suites available and actionable to people involved in participatory design activity. In other words, the goal of this work is to inform designers' intuition, not to replace it. I discuss the limitations to the field study and survey later.

From a design perspective, I chose to develop actionable knowledge to inform design activity over time. The four surgical suites I studied were in continual evolution during my fieldwork. Some surgical suites remodeled operating rooms, others added information technology (i.e., video feeds), enhancements to the whiteboards were made, and others yet upgraded medical technology. Given the continual evolution of the surgical suites, my design goal was to generate design knowledge that could inform surgical suite decision makers. In other words, I developed the design principles and design guidelines to communicate a set of criteria for good design solutions. I discuss the design limitations in two sections: design tools and design methodology.

Design tool limitations. There are four limitations to the design tools. First, I did not test the design principles (and design guidelines) directly with the survey. The information hotspots concept and the design principles and design guidelines informed the survey questions, but the survey questions did not capture them in their entirety. In this chapter, I revised the design principles and design guidelines by extrapolating from the survey data. However, these revised design principles and design guidelines remain untested in the field. In the future, designers should test these design principles and design guidelines in the field, preferably, within an evidence-based design practice.

Second, I was unable establish the weighting of the design principles associated with information hotspot formation and coordination outcomes. I based the weighting strategy in Table 6-2 on the quantity of support for each design principle received. Establishing the relative importance of each design principle (and design guideline) as well as possible interactions is possible with future work. An ordering according to importance will allow designers to focus on the most important. With regression analysis, it is possible to use the relative weights of each factor with respect to an outcome measure such as information exchange or coordination. However, this strategy will require a larger sample and a set of questions that map better onto the design guidelines than those used in my initial survey study.

Third, the design principles and guidelines currently are high level, whereas design solutions are detailed and particular in nature. At a high level, design principles and design guidelines describe the preferred state of factors such as the visibility between schedule board and control desk. The current evaluation checklist provides an approximate measure. As such, there is a gap between my evaluation checklist and the particular reality of specific surgical suites. Future work is necessary to determine how detailed the evaluation criteria of a surgical suite need to be to predict information exchange and coordination outcomes. For instance, there are various solutions proposed for XL Surgical Suite (Chapter 4). How do the different solutions providing visibility between schedule board and control desk (i.e., video link, window and audio link, face-to-face communication, etc.) compare? With which solutions is coordination faster and stress lower? I propose to develop different levels of sensitivity for my evaluation tool. In future work, different levels of sensitivity for each design principle should be tested for predictive power for outcome measures.

Fourth, the design principles and design guidelines resulted from the study of coordination processes around schedule boards in surgical suites. Future work is necessary to determine if they generalize to other domains within the healthcare setting (e.g., emergency departments). The evidence-based design paradigm can provide a framework for testing the design principles and design guidelines in other domains.

Design methodology limitations. To achieve my long-term design goal of informing decision makers on how the design of surgical suites "ought to be," field-tested design tools are necessary. As such, the design methodology implemented in this dissertation demonstrates part of a larger research trajectory. Future work will address this shortcoming by framing the design methodology into the larger evidence-based design paradigm. Within the evidence-based design paradigm, others could use the design principles and design guidelines to inform their own design activity, hypothesize performance improvements, measure the actual performance, and then update the surgical suite design tools to reflect their findings. Future research needs to determine if the design tools lead to better surgical suites. As more evidence emerges, the design principles and guidelines may require revision.

6.2.2 HCI Research

To design better surgical suites and information artifacts, it is important to understand how architecture and information affect information exchange and coordination outcomes in surgical suites with electronic schedule boards. From a human-computer interaction research perspective, one limitation is the lack of electronic displays in the fieldwork of the four surgical suites, and the small number of respondents with electronic schedule boards in the nationwide survey of surgical suite directors. In a follow-up study, I plan to study surgical suites with electronic displays using both fieldwork and a second national survey. Fieldwork will provide in depth understanding of how coordination unfolds in surgical suites with electronic schedule boards. A survey targeted to hospitals with electronic displays will provide a large enough sample to compare surgical suites with and without electronic displays.

Another limitation from the HCI perspective regards my focus on surgical suites in hospitals. Future research needs to explore linkages among architecture, information available, and workplace setting as critical factors in other settings. I anticipate that three changes in computing systems will further increase the importance of considering architecture, information, and workplace. For example, large display computing systems may sense gestures (e.g. Strickton & Paradiso, 1998); where people are located in relation to a large display and respond accordingly (e.g., Ju, Lee, & Klemmer, 2008); they may recognize who is present and respond accordingly (e.g., Congleton, Ackerman, & Newman, 2008); they may know where people are looking (e.g., Stiefelhagen, Finke, Yang, & Waibel, 1999; Zhang, Toth, Deng, Guo, & Yang, 2008); and they may recognize different behavior patterns among people who gather around a display and respond accordingly (e.g., Smith, Ba, Gatica-Perez, & Odobez, 2006; Bernardin & Stiefelhagen, 2007). As large displays incorporate this functionality (found in some prototypes today), the impact of the architecture environment on the success of information systems will increase.

Another area of where the architecture will affect deployment success regards sites where large display systems and hand-held systems coexist. In his seminal paper on ubiquitous computing, Mark Weiser describes a workplace with hundreds of computers embedded into the walls, wall-sized displays, and hand-held computer devices support human work activity (1991). Weiser describes computer systems that recognize who is in the space and display information accordingly. Missing from the ubiquitous computing vision is how the architecture of the built environment plays a role in supporting human work activity. Clearly, with ubiquitous computing human-computer interaction the boundary between the built environment and technology blur. The role of the architecture of the built environment within ubiquitous computing systems is an understudied area (McCullough, 2004). The architecture of the built environment shapes where people move, sit, and pause. As such, the architecture of the built environment is part of the interface (Mark, 1999). Thus, deployment success depends in part on the architecture of the built environment in which it is located. The location of the large displays and the configuration of the architecture environment are associated with how people move and pause around a large display. Conversely, the location of the large displays and the architecture may affect people's use of mobile displays in a setting. More generally, the system designers must consider the architecture of the deployment site when designing a large display based user interface system (Huang, 2007, Huang et al., 2008).

So far, I discussed the activity around one large display. How does the architecture around multiple networked large displays affect coordination? For example in a surgical suite, when the charge nurse uses one large display, and the charge anesthesiologist uses another one, how do the respective architecture settings around each display affect coordination? More empirical work is required to answer these questions.

Next, I speculate on how the concept of information hotspots can provide insights for the development of new technology and the placement of existing technology in the built environment of surgical suites. In healthcare settings, ubiquitous computing (Weiser, 1991), pervasive computing (e.g., Bardram et al., 2007), and ambient intelligence (e.g., Aarts, Harwig & Schuurmans, 2002) increasingly guide research prototypes and commercial applications. In these post-desktop visions of the surgical suite, computers are embedded into the surrounding physical environment. Surgical suite staff may interact with wall-sized displays integrated into the surgical suite that provide schedule information, staff location and patient status (e.g., Bardram et al., 2006); they might obtain their information via hand-held devices (e.g., PDAs, tablet PCs). The use of hand held devices is on the rise especially among younger physicians (Garritty & El Emam, 2006). Some surgical suites are integrating large electronic displays and small hand-held devices (e.g., Favela, Rodriguez, Preciado & Gonzalez, 2003). In the more distant future, pervasive computation might support the activities of the surgical suite naturally, without requiring explicit interaction with computing devices (e.g., Mark, 1999).

Although the results of my study do not speak directly to these future scenarios of technology use in the surgical suite, the concept of information hotspots can be used to draw implications for design of such systems. In the remainder of this section, I describe some of these implications as they pertain to large electronic displays, and hand-held devices.

Large electronic displays. In Chapter 5, I discussed some of the ways that introducing large electronic displays into the surgical suite might change the process of coordination. For example, the fact that there can be multiple identical displays increases the availability of the information but reduces the chances that staff members will cross paths while accessing that information.

My studies in conjunction with the concept of information hotspots suggest four considerations regarding these large electronic schedule displays. First, the displays should meet the basic architectural requirements for manual whiteboards. For example, they should be large enough to provide an overview of the surgery schedule and provide complete information, and they should be positioned in areas away from foot traffic. Second, interaction with the display should be as natural and easy as interaction with a manual whiteboard. My field data suggest that surgical suite coordinators tend to delegate complicated user interaction to clerks (e.g., log-in, keyboard, and mouse), and this delegation process can reduce coordination speed. Finally, designers should find new ways to create awareness of others' activities and support informal communication when the presence of multiple identical displays reduces actual physical collocation around the schedule board. Bardram et al. (2006) created a large display system that shows who is present in what operating room to support work coordination. A similar mechanism for showing who is present at which schedule board could be quite valuable.

Technology solutions to these problems of awareness and informal interaction introduced by electronic displays could draw on earlier media spaces research (e.g., Kraut et al., 1990; Dourish & Bellotti, 1992). For example, live audio and video feeds could connect areas around electronic schedule boards, similar to VideoWindow (Kraut et al., 1990). One display could provide a shared view onto the schedule board and a second wall-sized video feed could provide views onto the people present. The location of the video cameras and displays would require careful consideration so that people could look at the schedule board as if standing side by side and make eye contact when facing each other. Alternatively, cheaper solutions could make use of Bluetooth or other signaling properties of the phones staff members already carry with them. When in close proximity to a display, these phones could communicate the presence of their owners in the environment, which in turn could be displayed on the other electronic schedule boards via the people's names, photographs, or icons (e.g., Carter, Mankoff, & Heer, 2007). To initiate discussion between sites, people would simply use their phones.

Privacy is an often-cited concern when sensors and other data sources provide awareness of a user's physical and social environment. Hong & Landay (2004) developed an infrastructure to simplify the task of creating privacy sensitive applications. My fieldwork highlighted privacy concerns regarding information displayed on the schedule board. As such, large displays should be aware of their own location in the hospital (e.g., public area, staff only area, and so forth), assess who is present (e.g., staff only, public, and so forth), and display information accordingly such that patient privacy is protected. Likewise, large displays capable of sensing people's location can enhance information displayed to facilitate reading or hide sensitive information accordingly.

Small displays. In some surgical suites there are no large displays, either manual or electronic. Instead, hand-held devices allow staff members to send and receive schedule updates. From an information hotspots perspective, sole reliance on small displays creates three challenges for design. First, providing an overview of the surgical schedule in surgical suites with many operating rooms and surgeries is difficult on a small display and may require zooming, scrolling, or clicking through multiple screens. Second, information needs vary according to a person's role in the surgical suite; thus hand-held devices should be able to adjust display content accordingly. Third, hand-held devices may decrease congregating activity in central locations making finding people more difficult. Small devices can provide location information.

Recent work has tackled the problem of displaying large amounts of information on small devices for content such as newspapers or websites. For example, Buyukkokten, Garcia-Molina, Paepcke, & Winograd, (2000) made a system that dynamically generates summary views with the link structure and content of web pages on small displays. Lam & Baudisch (2005) developed a system that combines thumbnails and a summary of the text contained in the web news articles.

Other work has addressed the need for customizability in displayed content. For example, Wobbrock, Forlizzi, Hudson, & Myers (2002) developed a system that provides scalable thumbnails of webpages and allows end users to generate windows for areas of interest (i.e., links, newsfeeds), thus avoiding the need to scroll or zoom into the webpage. Baudisch, Xie, Wang, & Ma (2004) created collapse-to-zoom, a system to view webpages on small screens allowing users to remove irrelevant content.

Promising tools and techniques have also been developed to provide location information. Mobile devices that provide users with colleagues' context and location information can facilitate communication at appropriate moments (Ljungstrand, 2001). For instance, location systems based on active badges provide location information of staff (Want, Hopper, Falcão & Gibbon, 1992). However, willingness of staff to provide location information and privacy concerns may vary according to location and task at hand (e.g., Ackerman, 2004; Jones, Grandhi, Whittaker, Chivakula, & Terveen, 2004).

6.2.3 Behavioral Research

Finally, there are several limitations to the behavioral research described in this dissertation. I describe these limitations in two sections regarding fieldwork and survey.

Fieldwork. First, my field observations were limited to observing one location at a time (i.e., around the schedule board and control desk). I focused on coordination that occurred around the schedule board and control desk. In surgical suites, multiple actors distributed in space coordinate schedule changes. Surgical suite staffs move from one specialized space to the next to provide patient care (i.e., check-in area, patient holding area, operating room, and post-anesthesia care unit). A single investigator conducting field research in this complex and dynamic setting will necessarily miss phenomena of interest. New fieldwork with multiple investigators observing multiple locations, multiple communication channels, and multiple actors can better study coordination as it unfolds throughout the surgical suite.

Second, in the field study, I collected partial data regarding communications. I noted if people around the schedule board were using the phone, pagers, and so forth but at times was unable determine conversation partners. Multiple simultaneous observers, as outlined above, allow a better understanding of the nature of communication patterns as they relate to architecture, information, and work setting. In addition, hospital confidentiality regulations did not allow me to record the content of these conversations. While it seems unlikely that hospital confidentiality regulations will change. It might be possible to ask workers about the general content of their messages in order to better track how information presented on large displays propagates through the surgical suite.

Third, in the field study, all four the schedule boards studied were manual. Two of the sites were supposed to deploy an electronic schedule board system but two years later still have not. I had planned to study the two surgical suites before and after the electronic schedule board deployments. As noted previously, future work is required to understand the impact of digital boards on coordination processes. Also of interest is how the transition from manual displays to electronic displays alters interactions among surgical suite staff. Furthermore, some systems can send updates to staff's portable devices in addition to displaying it on a large board. How will a mix of large schedule boards and small personal displays affect coordination? Will central information hotspot locations increase or decrease in importance? As new systems with multiple electronic displays and mobile information devices become more common, it is important to understand how architecture and information in different locations are associated with information exchange and coordination practices throughout the surgical suite.

Fourth, my analysis of the field data focused on who was present, and who interacted at the schedule board and control desk. I analyzed the data collected at the surgical suite level of analysis. With a team of observers, different levels of analysis are possible. More work is necessary to determine how significant differences in the architecture environment, information environment, and work environment affect coordination processes and outcomes at the group or team level (e.g., surgical suite nursing team, anesthesia team, and surgical team).

Fifth, I studied surgical suites that used both schedule boards and control desks. As such, the field study data do not address surgical suites that use only a schedule board, only a control desk, or neither. More fieldwork is necessary to learn how staff coordinate schedule changes in surgical suites that use only the control desk, or only a use schedule board, or neither?

Survey. Finally, the survey was limited in a number of respects, many of which mentioned previously. The questions did not completely capture the elements of the design guidelines, and some respondents did not answer architectural questions that required measurement (e.g., the size of the display board). Future iterations of the survey will improve on these flaws. Moreover, few respondents reported on surgical suites with electronic display boards, despite the rise in usage of these boards in recent years. The next survey will specifically target electronic display board users (which as shown in Chapter 5 tend to be hospitals with more beds and operating rooms). Finally, my assumption that each surgical suite would typically have just one type schedule board turned out to be incorrect. Half of the surgical suites with electronic boards also reported using a manual board. The new survey should focus on understanding why, how, and in what circumstances each type of schedule board is used.

6.3 Conclusion

In this dissertation, I demonstrated how aspects of the architecture of the built environment and information available on public displays are associated with communication and coordination in complex work environments. I used field studies in four surgical suites and a nationwide survey sent to surgical suite directors. The main contribution of this dissertation is the idea that the location of large schedule displays, the characteristics of the architecture around such displays, and the information available are associated with coordination processes and outcomes. More precisely, for the task of coordinating schedule changes in surgical suites, three factors are critical: a visual relationship between the schedule board and control desk in the surgical suite, traffic-free areas around the schedule board, and complete up to date schedule board information. These factors lead to greater congregating and faster coordination speed as predicted by the concept of information hotspots. Lower coordination stress resulted from faster coordination speeds.

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Appendix 1: Business Reply Mailer, Cover Letter, and Survey Tool

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL
FIRST-CLASS MAIL PERMIT NO 2358 PITTSBURGH PA

POSTAGE WILL BE PAID BY ADDRESSEE

ATTN: PETER SCUPELLI
HCII - NSH 3508
HUMAN-COMPUTER INTERACTION INSTITUTE
CARNEGIE MELLON UNIVERSITY
5000 FORBES AVE
PITTSBURGH PA 15213-9984

Carnegie Mellon

Human-Computer Interaction Institute
School of Computer Science
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, Pennsylvania 14213-3890

August 21, 2008

Ms. Florence Nightingale
Consola Hospital
575 Main St
Pittsburgh, PA 15201

Dear Ms. Nightingale,

I am writing to ask for your help with a nationwide Carnegie Mellon University research project to improve the design of surgical suites. Your expertise on this topic will be very valuable to this research and to improving clinical practice.

The purpose of the research is to learn which OR layouts and information displays can best support coordination and scheduling in surgical suites. You can help advance research on surgical suite design and information technology by taking a few minutes to complete the enclosed survey.

Answers are private and confidential. We will report survey results only as summaries in which no individual's answers can be identified. All information provided will be used only for research purposes. If you are interested in the results of the study, we are glad to send them to you.

I hope you will take some time to complete this brief survey. Thank you in advance for your time and effort. The survey team is being led by doctoral student Peter Scupelli. If you have any questions, feel free to contact me by email (*****@cs.cmu.edu) or phone (*** *** ****) or Peter by email (***@andrew.cmu.edu) or phone (*** *** ****).

Sincerely yours,

Signed By Hand

Sara Kiesler
Hillman Professor of Computer Science and Human-Computer Interaction
Human-Computer Interaction Institute
Carnegie Mellon University

National Surgical Suite Survey

Peter Scupelli
Human-Computer Interaction Institute
Carnegie Mellon University
phone: 412-535-2699
email: pgs@andrew.cmu.edu

This survey will be used to improve the design of surgical suites.

We are asking you to complete the survey about one surgical suite you manage.

Your answers will be kept private and confidential. Only aggregate data will be reported. Your name or hospital will not be revealed.

The survey should take approximately 15-20 minutes to complete.

Thank you very much for your help.

If you have questions while completing the survey, please call 412-535-2699 or email pgs@andrew.cmu.edu.

Start Here

1. What best describes your role? Check all that apply.
   - ( ) Administrator
   - ( ) OR Nurse
   - ( ) Anesthesiologist
   - ( ) Surgeon
   - ( ) Other (please describe) ________________________________

2. Circle how many surgical suites you manage below.
   We define surgical suite as a group of operating rooms managed as a unit.

   0 1 2 3 more

Please choose one surgical suite to answer the rest of the survey.

3. How many operating rooms (OR) are located in this surgical suite?
   _____ operating rooms

4. Does your surgical suite have the following? Check all that apply.
   - ( ) OR control desk
   - ( ) OR schedule display board
   - ( ) Charge nurse
   - ( ) Charge anesthesiologist

5. Which surgical services are provided each week? Check all that apply.

( ) Cardiac	( ) Pediatric
( ) General	( ) Plastic/Reconstructive
( ) Interventional Radiology	( ) Thoracic
( ) Neurosurgery	( ) Transplantation
( ) Ophthalmology	( ) Vascular
( ) Oral/Maxillofacial	( ) Urology
( ) Orthopedics	( ) Other ________________________
( ) Otorhinolaryngology	

SURGICAL SUITE WORK

6. On average, how many operating rooms are used each day in your suite?
   _____ operating rooms

7. On average, how many surgeries are completed each day in your suite?
   _____ surgeries

8. On average, how many surgeries are "added-on" or "wait-listed" to the OR schedule?
   _____ surgeries

9. On average, how many surgeries are cancelled on the day of surgery?
   _____ surgeries

10. On average, how many surgeries are delayed on the day of surgery?
    _____ surgeries

Surgical Suite OR Schedule Changes

11. On the day of surgery, how quickly do the following people learn about changes to the OR schedule?

	More than one hour later	Within one hour	Within thirty minutes	Within a few minutes	Almost immediately
Charge nurse	○	○	○	○	○
Charge anesthesiologist	○	○	○	○	○
Surgeons	○	○	○	○	○
OR nursing staff	○	○	○	○	○
Anesthesia staff	○	○	○	○	○

12. On the day of surgery, how often do people coordinate changes to the OR schedule using:

	Never	Rarely	Sometimes	Usually	Almost Always
Phone calls.	○	○	○	○	○
Overhead announcements.	○	○	○	○	○
Pager (or beeper) calls.	○	○	○	○	○
Face-to-face conversations at the OR schedule board.	○	○	○	○	○
Face-to-face conversations at the OR control desk.	○	○	○	○	○
Face-to-face conversations elsewhere in the surgical suite.	○	○	○	○	○

13. On the day of surgery, rate how often people find out about OR schedule changes by:

	Never	Rarely	Sometimes	Usually	Almost Always
Checking information posted on the OR schedule board.	○	○	○	○	○
Logging onto the computer OR schedule system.	○	○	○	○	○
Having face-to-face conversations during breaks in lounges, cafeterias, workrooms, break areas, etc.	○	○	○	○	○
Having face-to-face conversations in hallways.	○	○	○	○	○

2

14. Rate how much you agree or disagree with the following statements about your surgical suite.

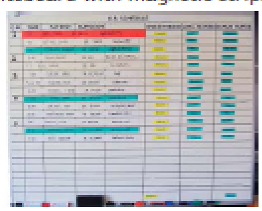
	Strongly disagree	Disagree	Agree somewhat	Agree	Strongly agree
There are few OR schedule changes each day.	○	○	○	○	○
People adapt easily to OR schedule changes.	○	○	○	○	○
It takes little effort to update the OR schedule board.	○	○	○	○	○
People have to run around to learn about OR schedule changes.	○	○	○	○	○
OR schedule changes are stressful.	○	○	○	○	○

OR SCHEDULE BOARD (Please continue to answer about the same surgical suite.)

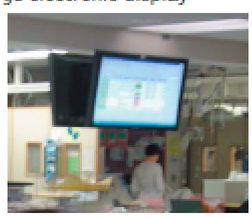
15. Which OR schedule board below is most like the one(s) used in your surgical suite?
Check all that apply.

( ) Handwritten whiteboard

( ) Whiteboard with magnetic strips



( ) Large electronic display



( ) Other (describe below)

____

____

____

____

____

____

16. How many of each type of OR schedule boards are used in your surgical suite?

____ Handwritten whiteboard(s)
____ Whiteboard(s) with magnetic strips
____ Large electronic display(s)
____ Other (please specify) ______________________

3

To answer the survey questions below, please choose the OR schedule board with the most useful schedule and staff information.
If there is no OR schedule board, skip to question 31.

17. Approximately what size and position is this OR schedule board?
Height ________ Width ________
Distance from bottom of this OR schedule board to the floor __________

18. What information is available on this OR schedule board? Check all that apply.

( ) Time of surgery	( ) Surgeon	( ) Special equipment
( ) OR #	( ) Anesthesiologist / anesthetist	( ) Type of patient transport
( ) Patient name / initials	( ) Procedure	( ) Pre-op location
( ) Consent issues	( ) Scrub nurse	( ) Post-op destination
( ) Patient issues	( ) Circulator nurse	( ) Other(s) ________________

19. Is this OR schedule board in a sterile corridor or in a main hallway connected to a sterile corridor?
(a) Yes
(b) No

20. Approximately how far is this OR schedule board from the closest sterile corridor?
_____ feet away

21. Approximately how far is this OR schedule board from the OR control desk?
_____ feet away
_____ There is no OR control desk

22. Are there any physical barriers (i.e., walls, doors, or furniture) between this OR schedule board and the OR control desk?
(a) Yes
(b) No
(c) No OR control desk

23. How far away can you stand from the OR schedule board and still read most of it?
(a) Less than two feet away
(b) Up to four feet away
(c) Up to six feet away
(d) Up to eight feet away
(e) More than eight feet away

Activities Around the OR Schedule Board

24. How many people can comfortably gather around the OR schedule board?
(a) Two persons or less
(b) Three to four persons
(c) Five to six persons
(d) Seven to nine persons
(e) Ten or more persons

25. How often do people stop by and sit around the OR schedule board?

(a) Never
(b) Rarely
(c) Occasionally
(d) Fairly often
(e) Almost continuously

26. How often do people drink beverages or eat food near the OR schedule board?

(a) Never
(b) Rarely
(c) Occasionally
(d) Fairly often
(e) Almost continuously

27. How many papers, posters, or contact lists are posted near or around the OR schedule board?

(a) None
(b) 1 to 10 items
(c) 11 to 20 items
(d) 21 to 30 items
(e) 31 or more items

28. How often are the following persons around the OR schedule board each day?

	Never	One or two times	A few times	Several times	Almost continually
Charge nurse	o	o	o	o	o
Control desk staff	o	o	o	o	o
OR nurses	o	o	o	o	o
Charge Anesthesiologist	o	o	o	o	o
Anesthesia team members	o	o	o	o	o
Surgeons	o	o	o	o	o
Housekeeping staff	o	o	o	o	o

29. Who updates the OR schedule board each day and how often do they update it?

	Never	One or two times	A few times	Several times	Almost continually
Charge nurse	o	o	o	o	o
Control desk staff	o	o	o	o	o
OR nurses	o	o	o	o	o
Charge Anesthesiologist	o	o	o	o	o
Anesthesia team members	o	o	o	o	o
Surgeons	o	o	o	o	o
Housekeeping staff	o	o	o	o	o

OR Schedule Board Evaluation

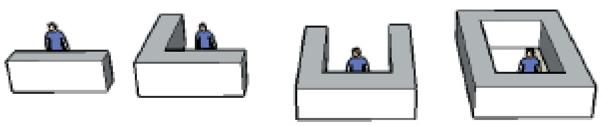
30. Rate how much you agree or disagree with the following statements.

	Strongly disagree	Disagree	Agree somewhat	Agree	Strongly agree
People at the OR schedule board and OR control desk can see each other.	○	○	○	○	○
Conversations at the OR schedule board can be overheard at the OR control desk.	○	○	○	○	○
There is enough space to post information near or around the OR schedule board.	○	○	○	○	○
The OR schedule board is large enough to display necessary information.	○	○	○	○	○
Foot traffic interferes with people reading the OR schedule board.	○	○	○	○	○
The OR schedule board is easy to update.	○	○	○	○	○
Updates to the OR schedule board are timely.	○	○	○	○	○

OR CONTROL DESK (Please continue to answer about the same surgical suite.)

If there is no OR control desk skip to question 43.

31. Which OR control desk is most like the one used in your surgical suite?



(a) Linear counter

(b) L-shaped counter

(c) U-shaped counter

(d) Rectangular shaped counter

____

(e) Other (specify above)

32. Is the OR control desk in a sterile corridor or on a main hallway connected to a sterile corridor?

    (a) Yes

    (b) No

33. Approximately how far away is the OR control desk from the nearest sterile corridor?

    _____ feet away

6

34. Are there any physical barriers (i.e., walls, doors, or furniture) between the OR control desk and the nearest sterile corridor?
(a) Yes
(b) No
(c) No OR control desk

Activities Around the OR Control Desk

35. From how many counters can people stop by to interact with OR control desk staff?
(a) None
(b) One counter
(c) Two counters
(d) Three counters
(e) Four or more counters

36. How many people can comfortably gather around this OR control desk?
(a) Two or less
(b) Three to four
(c) Five to six
(d) Seven to nine
(e) Ten or more

37. How often do people stop by and sit around the OR control desk?
(a) Never
(b) Rarely
(c) Occasionally
(d) Fairly often
(e) Almost continuously

38. How often do people drink beverages or eat food near the OR control desk?
(a) Never
(b) Rarely
(c) Occasionally
(d) Fairly often
(e) Almost continuously

39. How many papers, posters, or contact lists are posted near or around the OR control desk?
(a) None
(b) 1 to 15 items
(c) 16 to 30 items
(d) 31 to 45 items
(e) 46 or more items

40. Who routinely staffs the OR control desk? Check all that apply.
( ) Charge nurse
( ) Clerk / Receptionist
( ) OR nurse
( ) Surgical staff
( ) House cleaning
( ) Other (specify) ______________________

41. How often are the following persons around the OR control desk each day?

	Never	Once a day	Twice a day	Several times a day	Almost continually
Charge nurse	O	O	O	O	O
OR nurses	O	O	O	O	O
Charge anesthesiologist	O	O	O	O	O
Anesthesia team members	O	O	O	O	O
Surgeons	O	O	O	O	O
Housekeeping staff	O	O	O	O	O

OR Control Desk Evaluation

42. Rate how much you agree or disagree with the following statements.

	Strongly disagree	Disagree	Agree somewhat	Agree	Strongly agree
There is enough space to post information near or around the OR control desk.	O	O	O	O	O
The OR control desk is in a central location in the surgical suite.	O	O	O	O	O
Foot traffic interferes with people stopping by the OR control desk.	O	O	O	O	O

HOSPITAL

43. Academic affiliations (check one).
( ) University hospital.
( ) Affiliated with another academic institution.
( ) Not affiliated with an academic institution.

44. Approximately how many beds are in the hospital?
______ beds

Optional

45. To receive the survey results, please fill out the following:

Name & Title ____

Address ____

____

____

E-mail address: ____

46. Is there anything else? ____

8

Thank you very much for completing the survey.

Again, your answers will be kept private and confidential.
Only aggregate data will be reported.
Your name or hospital will not be revealed.

Appendix 2: Demographics of Respondents

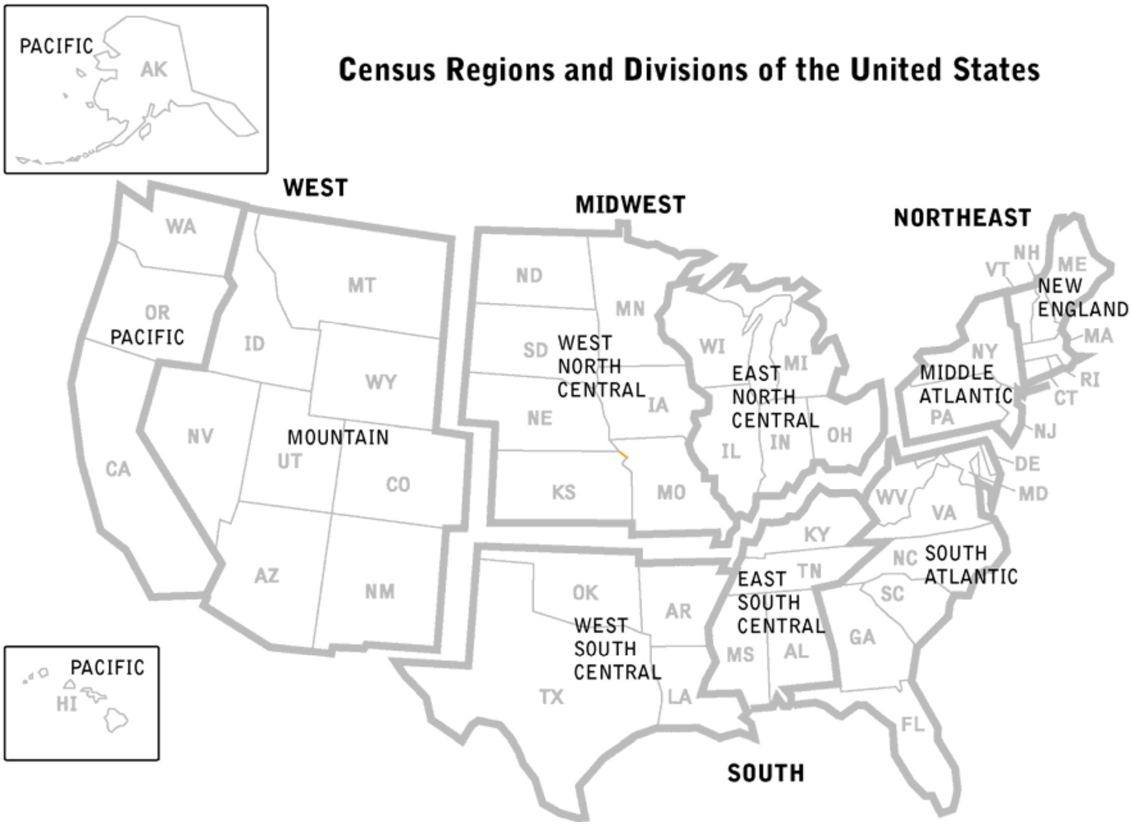


Figure 2-1. A map of the United States with the U.S. Census Bureau regions and divisions that I used to assign surveys to a geographic area (see Table 2.1).

Table 2-1. Average of surgical suite directors by census region.

	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific	Total
Responded survey [1] (N=113)	3.39%	15.25%	23.73%	11.02%	13.56%	10.17%	4.24%	8.47%	10.17%	100%
Sample sent survey [2] (N=1200)	4.25%	10.67%	14.50%	12.75%	16.50%	9.25%	13.75%	7.50%	10.83%	100%
Mailing list[3] (N=3827)	4.02%	10.53%	16.15%	13.17%	16.15%	8.70%	13.14%	6.92%	11.21%	100%

[1] The first row contains the percentages for the 113 postmarked surveys.
[2] The second row contains the percentages for random sample of 1200 surgical suite directors who were mailed surveys.
[3] The third row has percentages for the complete SK&A mailing list for 3827 surgical suite directors.

Table 2-2. Type of hospital for survey respondents, sample of surgical suite directors sent a survey, and all surgical suite directors listed on the SK&A information mailing list.

	(a) Survey respondents[4] N=113	N	Random sample sent survey N=1200	N	Whole list N=3827	N
Critical care access	7.08%	8	6.33%	76	6.51%	249
Children	5.31%	6	1.83%	22	1.62%	62
General acute care	71.68%	81	73.83%	886	72.56%	2777
Geriatric care	0%	0	0.08%	1	0.05%	2
Long term acute care	7.96%	9	10.67%	128	11.24%	430
Military	1.77%	2	0.92%	11	0.76%	29
Mental health	0%	0	0%	0	0.05%	2
Nursing homes	0.88%	1	0.75%	9	1.33%	51
Osteopathic	1.77%	2	0.67%	8	0.63%	24
Prisons	0%	0	0.08%	1	0.08%	3
Rehabilitation centers	0%	0	0.25%	3	0.18%	7
Substance abuse	0%	0	0.08%	1	0.03%	1
University teaching	1.77%	2	1.92%	23	2.35%	90
Veteran administration	1.77%	2	2.58%	31	2.61%	100
Total	100%	113	100%	1200	100%	3827

Table 2-3. Crosstab of hospital type by hospital affiliation.

	University hospital	Affiliated	Not affiliated	Total
Critical Care Access	0	1	7	8
Children	3	1	2	6
General Acute Care	3	17	58	78
Long Term Acute Care	1	2	6	9
Military	0	1	1	2
Nursing Homes	0	0	1	1
Osteopathic	0	2	0	2
University/Teaching	1	0	1	2
Veteran Administration	0	2	0	2
Unspecified	0	3	16	19
Total	8	29	92	129

[4] Of the 135 survey respondents, the hospital types for 22 respondents are missing in the dataset. Hence, I calculated the response rate by type of hospital for the 113 hospitals identified.

Table 2-4. Statistics for number of operating rooms by hospital type.

Hospital type	Mean	N[5]	Minimum	Maximum	Std. Deviation
Critical Care Access	2.38	8	1	4	0.92
Children	9.33	6	2	14	3.98
General Acute Care	8.36	80	1	25	5.71
Long Term Acute Care	5.63	8	1	25	7.89
Military	9.00	2	7	11	2.83
Nursing Homes	1.00	1	1	1	0.00
Osteopathic	14.50	2	8	21	9.19
University/Teaching	22.50	2	13	32	13.44
Veteran Admin	8.00	2	8	8	0.00
Unspecified	4.20	20	1	9	2.46
Total	7.50	131	1	32	5.96

Table 2-5. Type of schedule board (e.g., manual vs. electronic) by hospital type.

Hospital type	Manual schedule board	Electronic schedule board
Critical Care Access	8	0
Children	4	2
General Acute Care	62	17
Long Term Acute Care	7	0
Military	2	0
Nursing Homes	1	0
Osteopathic	1	1
University/Teaching	1	1
Veteran Admin	2	0
Unspecified	19	1
Total	107	22

[5] Note- Four survey respondents did not answer the question regarding the number of operating room in the surgical suite.

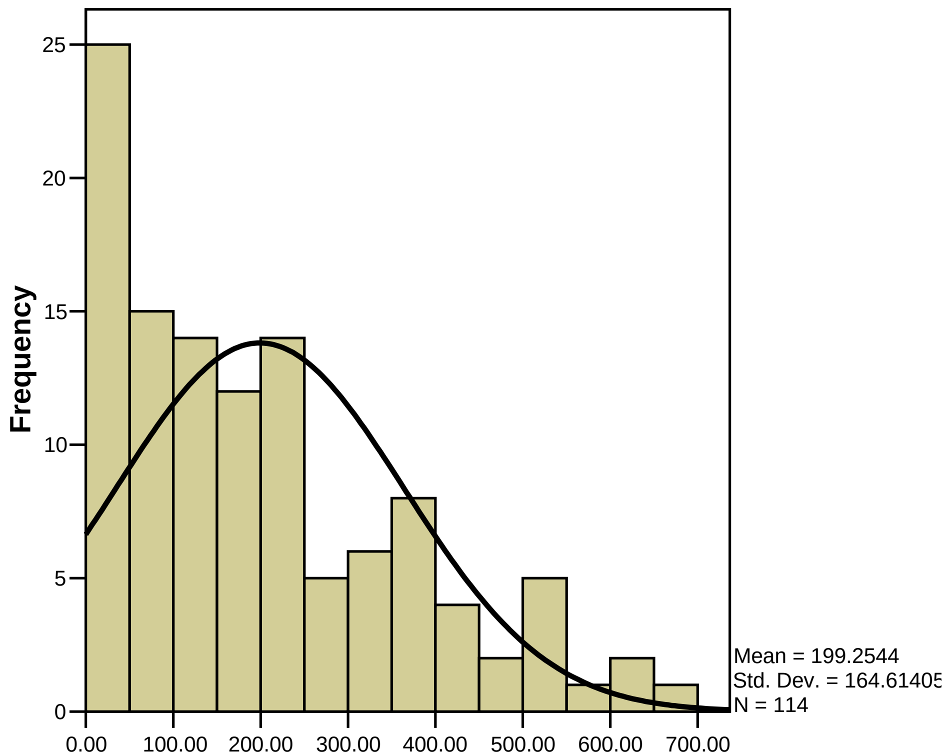


Figure 2-2. Hospital beds measured as the number of beds in hospitals with surgical units.

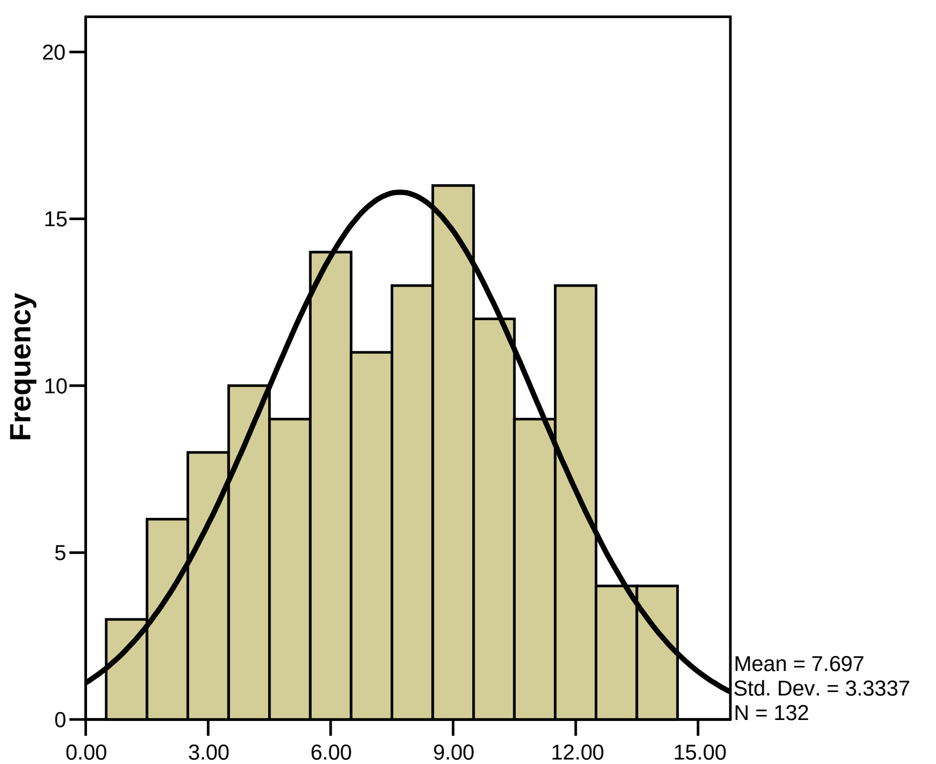


Figure 2-3. Number of surgical services present in surgical units.

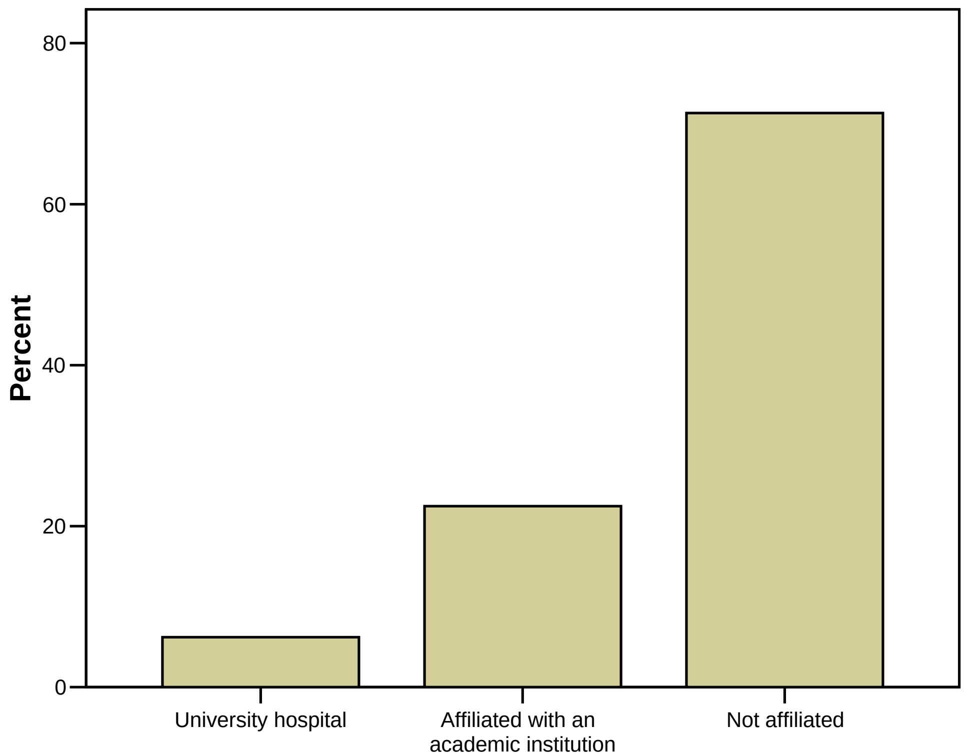


Figure 2-4. Hospital affiliation for surgical suites.

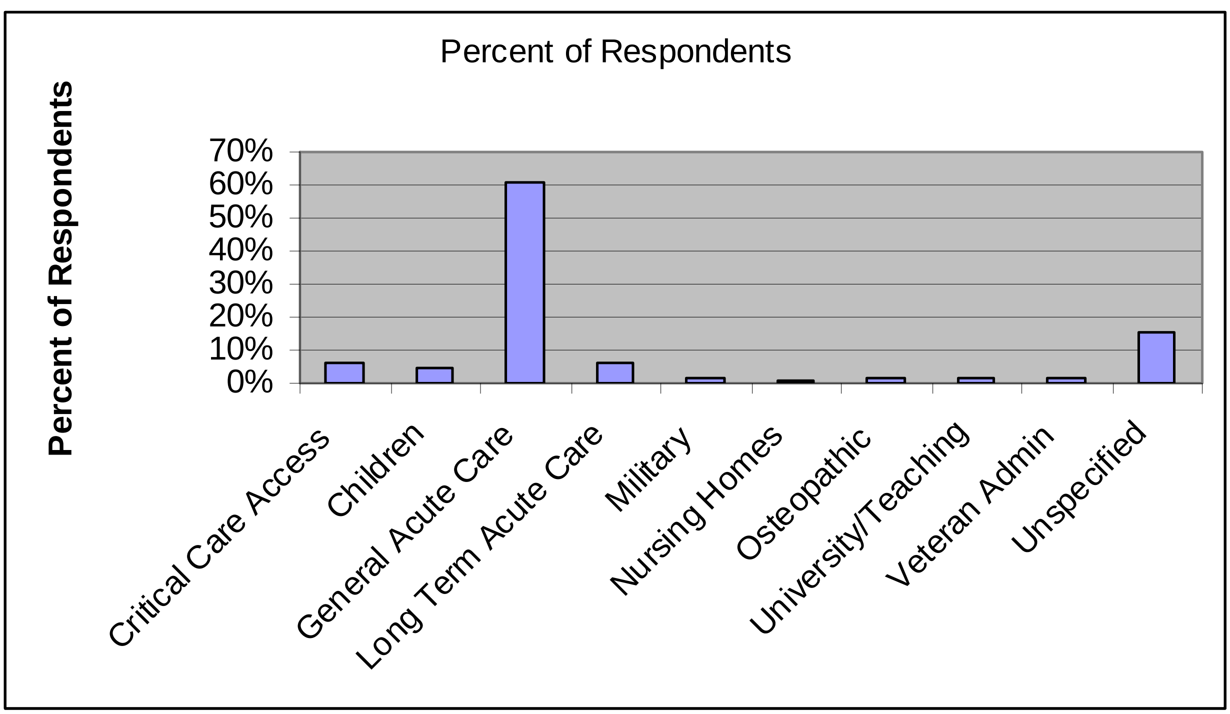


Figure 2-5. Hospital type by percent of respondents.

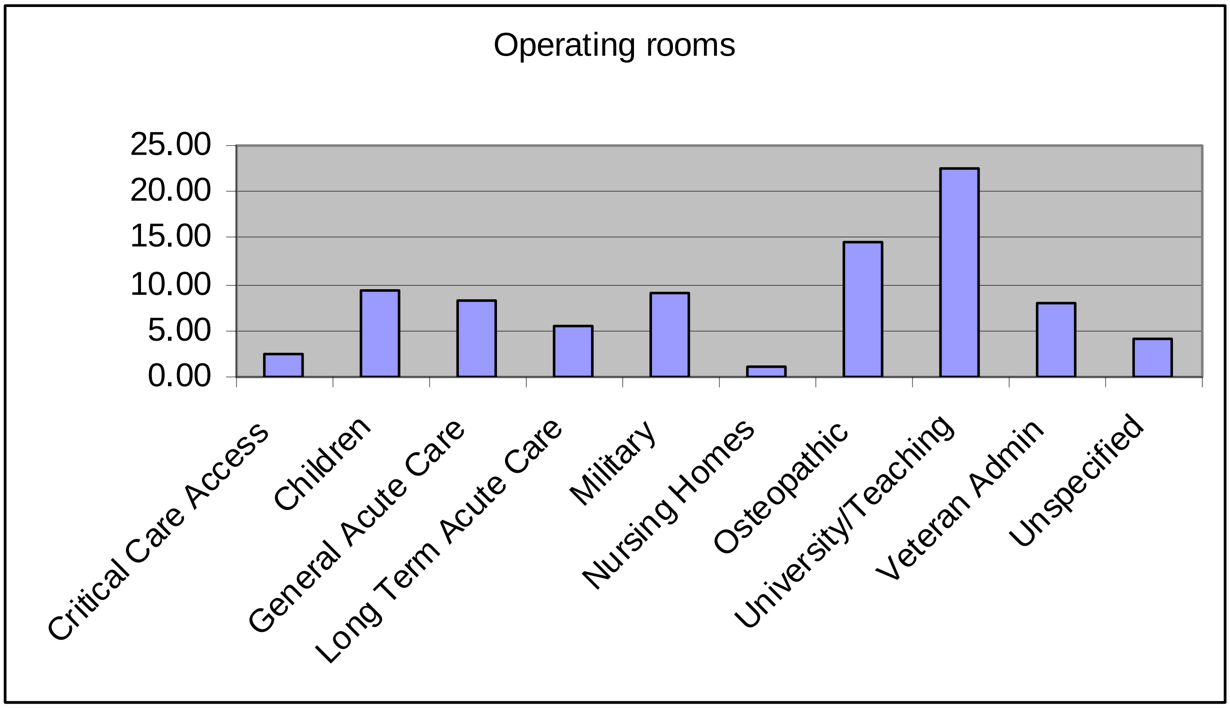


Figure 2-6. Hospital type by number of operating rooms.

Appendix 3: Relationships among key variables

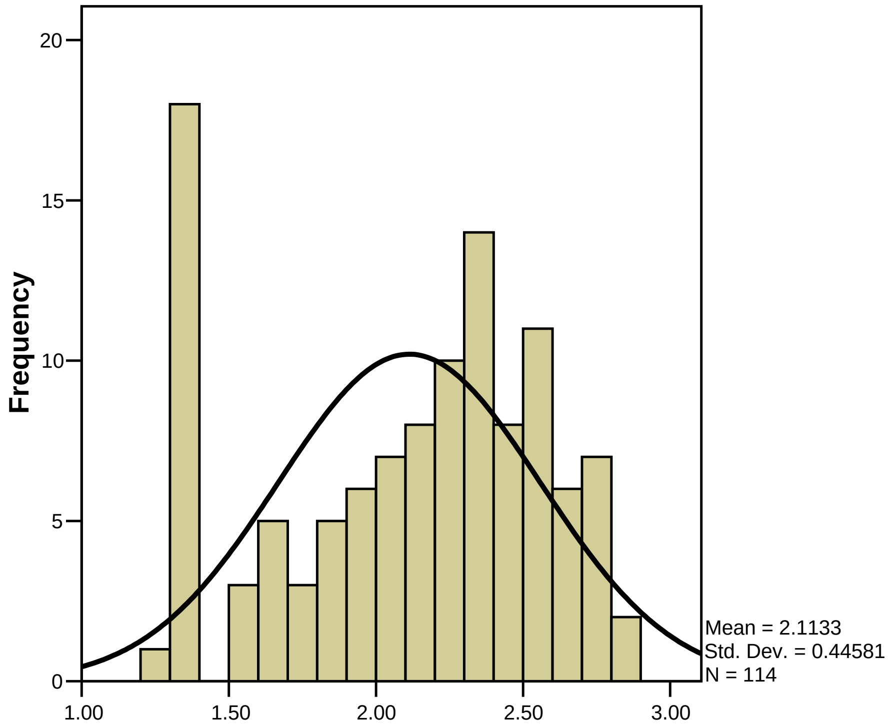


Figure 3-1. Number of log hospital beds for survey respondents.

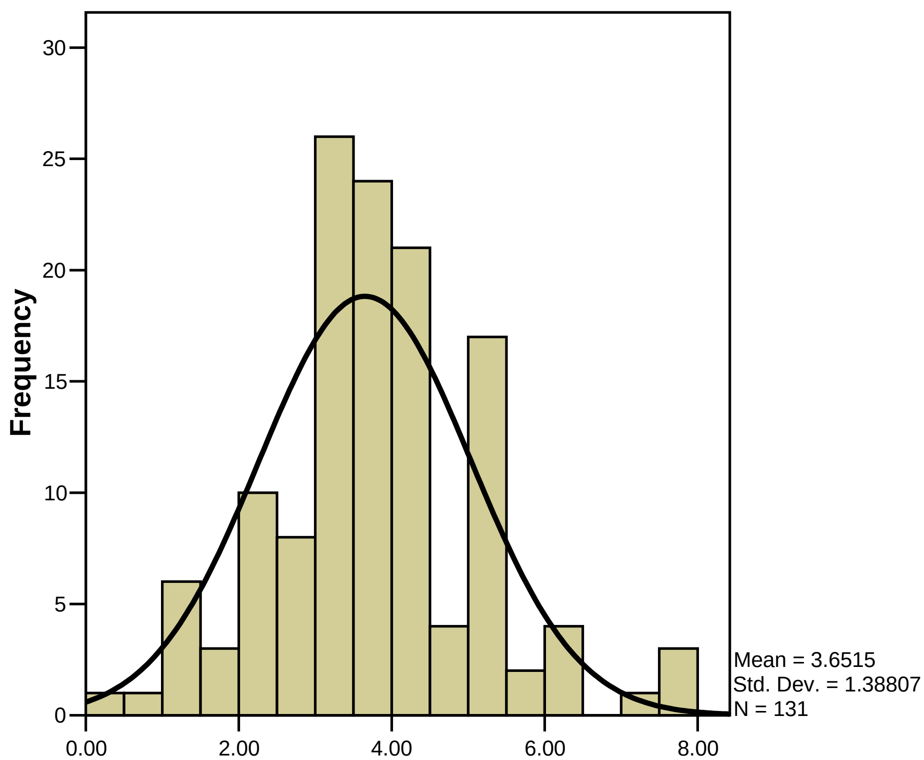


Figure 3-2. Surgeries per room measured as mean surgeries completed per room per day.

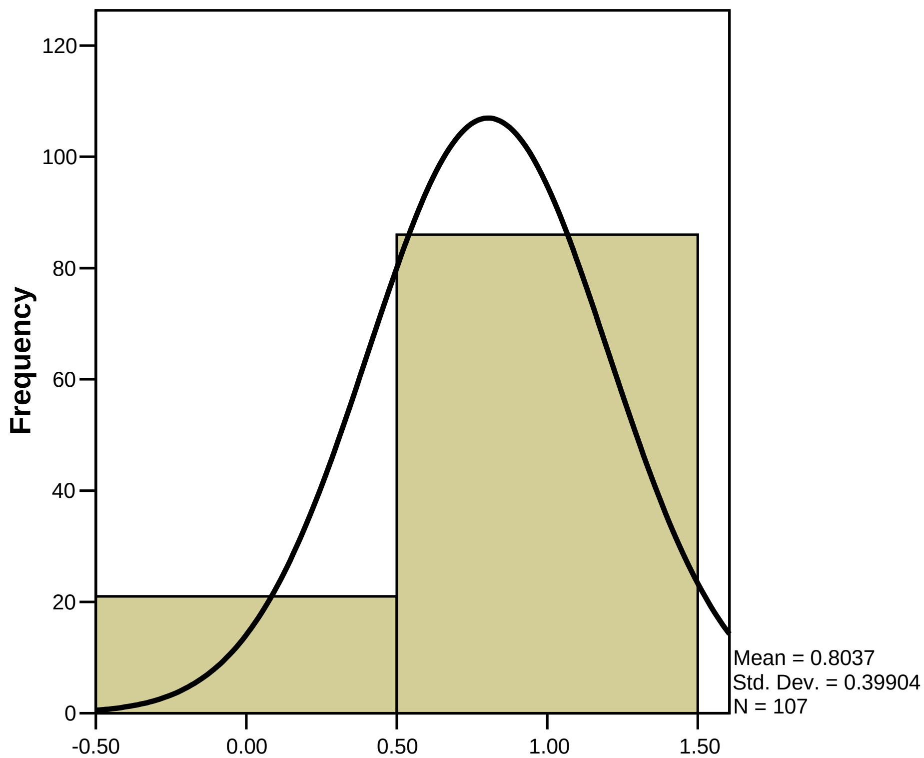


Figure 3-3. Visibility between the schedule board and control desk (no = 0, yes = 1).

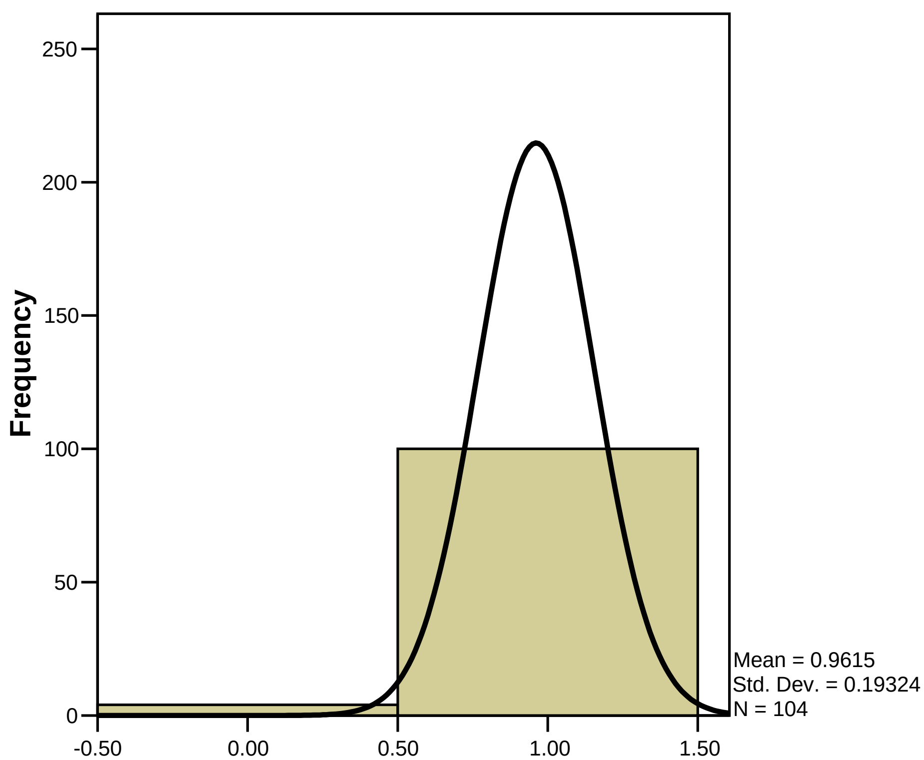


Figure 3-4. Easy updates measured as the schedule board is easy to update; (no = 0, yes = 1).

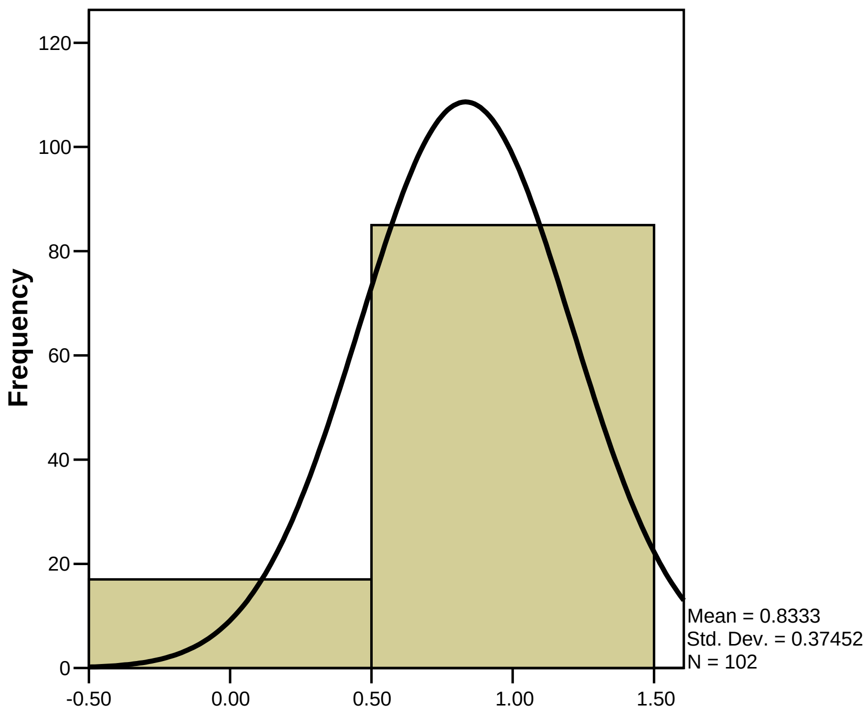


Figure 3-5. Centrality of schedule board with respect to the main hallway leading to the sterile corridor (no =0, yes =1).

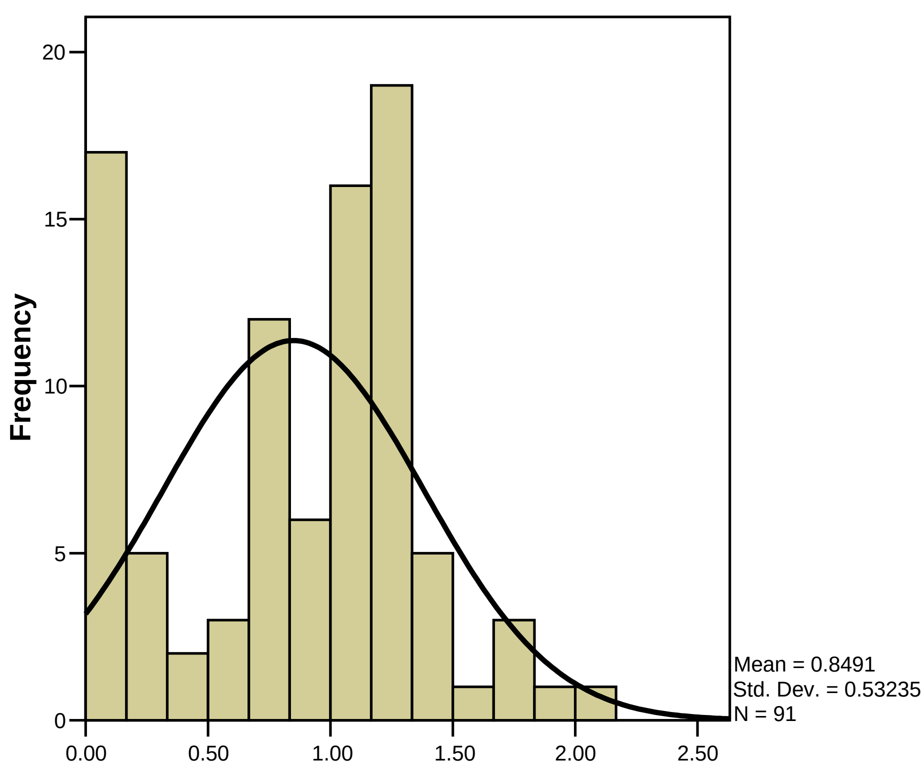


Figure 3-6. Log Distance between the schedule board and the sterile corridor.

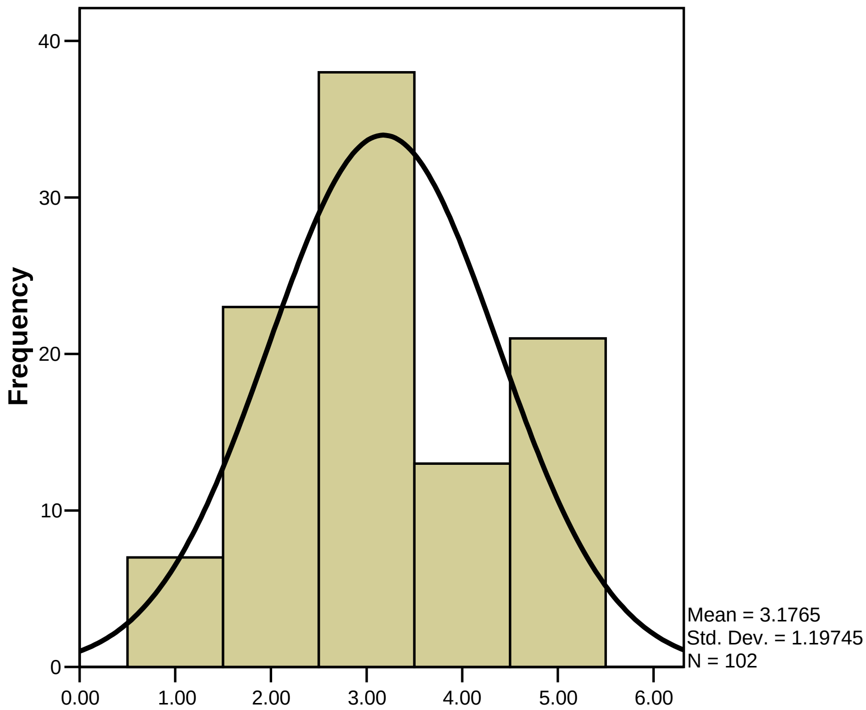


Figure 3-7. Gathering measured as how many people can gather comfortably around the schedule board (1= two persons or less, 2=three to four persons, 3= five to six persons, 4=seven to nine persons, 5= ten or more persons).

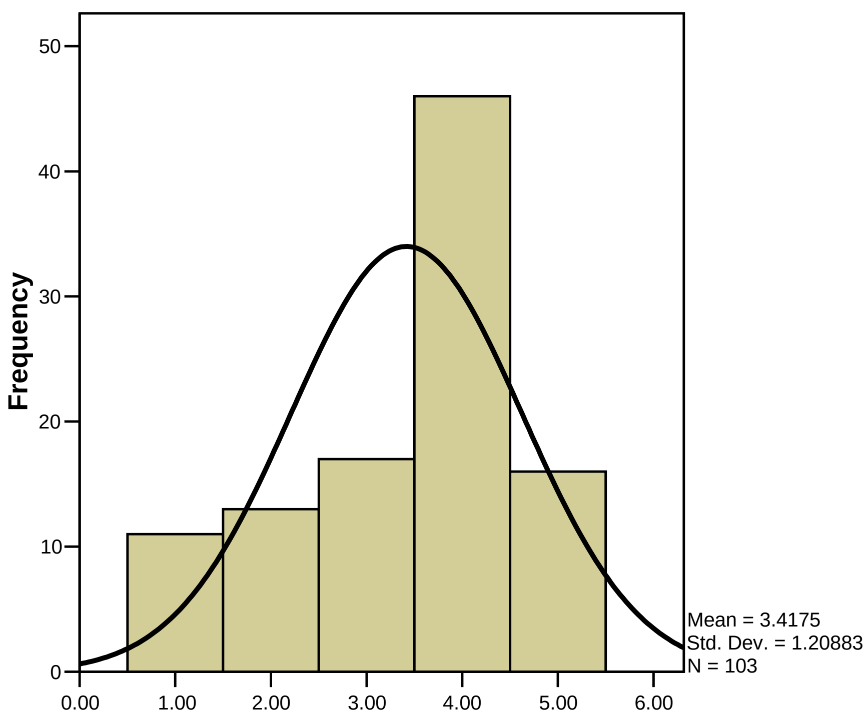


Figure 3-8. Traffic free measured as foot traffic interferes with people reading the schedule board (1 Strongly disagree to 5 Strongly agree); the question was reverse coded.

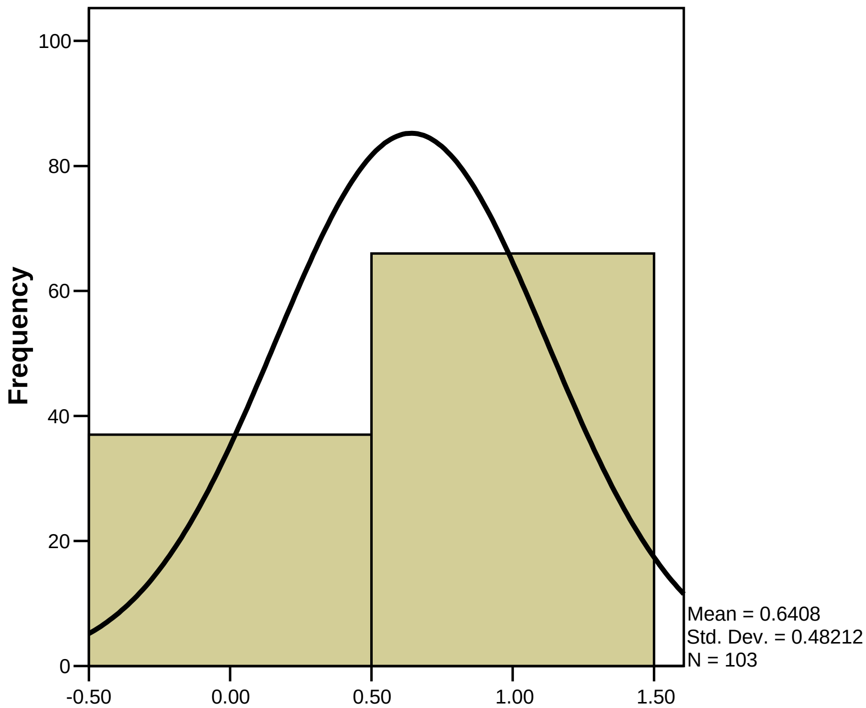


Figure 3-9. Barrier free measured as are there any physical barriers between the schedule board and the nearest sterile corridor; the question was reverse coded (no = 0, yes = 1).

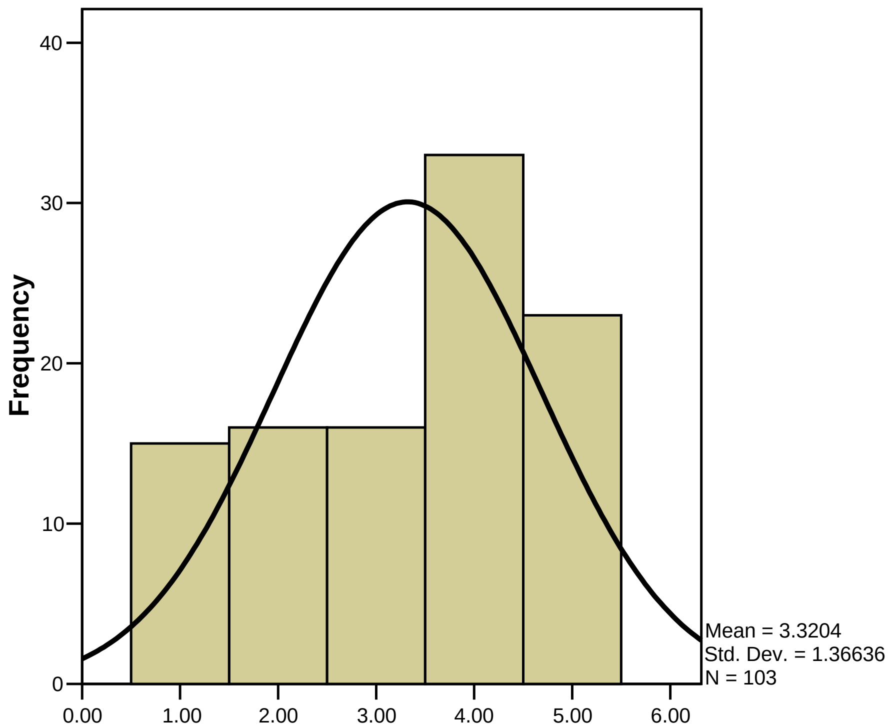


Figure 3-10. Sitting around schedule, measured as how often do people stop by and sit around the schedule board (1 = Never, 2 = Rarely, 3 = Occasionally, 4 = Fairly often, 5= Almost continually).

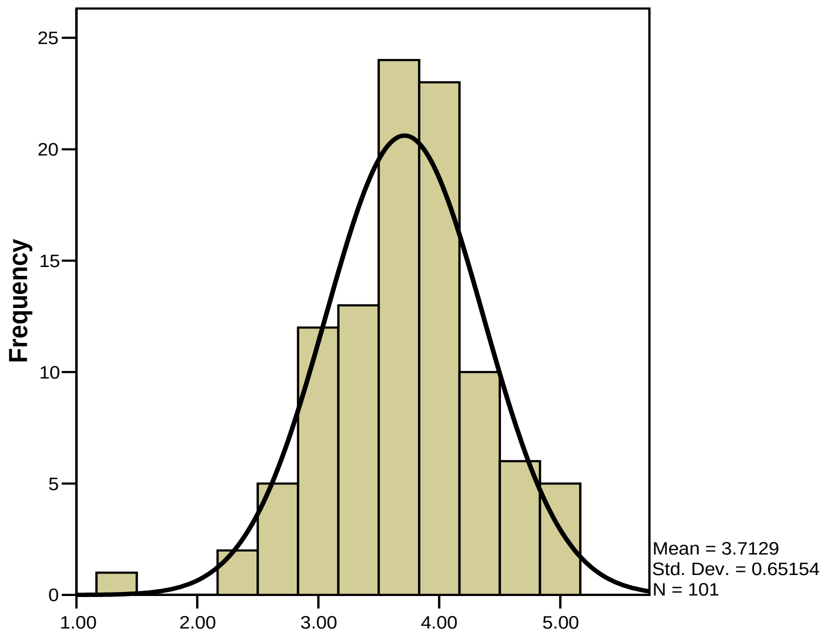


Figure 3-11. Face-to-face hotspots measured as the mean for three items on a five point frequency Likert scale (1= Never, 2= Rarely, 3=Sometimes, 4=Usually, 5=Almost always). On the day of surgery, how often do people coordinate schedule changes by: (a) Having face-to-face conversations at the schedule board. (b) Having face-to-face conversations at the control desk (c) Checking information on the schedule board.

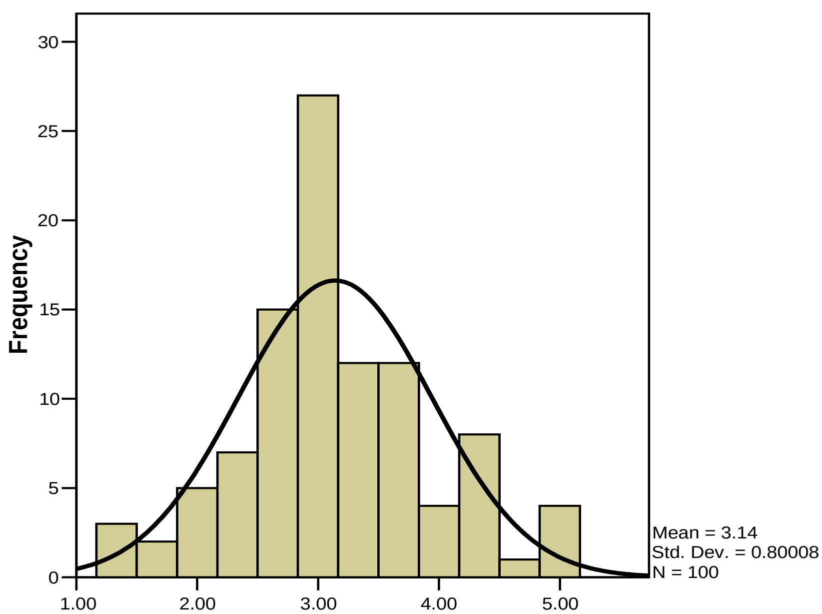


Figure 3-12. Face-to-face elsewhere measured as the average score for 3 items on a five point frequency Likert scale (1= Never, 2= Rarely, 3=Sometimes, 4=Usually, 5=Almost always). On the day of surgery, how often do people coordinate schedule changes by: (a) Having face-to-face conversations during breaks in lounges, cafeterias, workrooms, break areas, etc. (b) Having face-to-face conversations in hallways. (c) Face-to-face conversations elsewhere in the surgical suite.

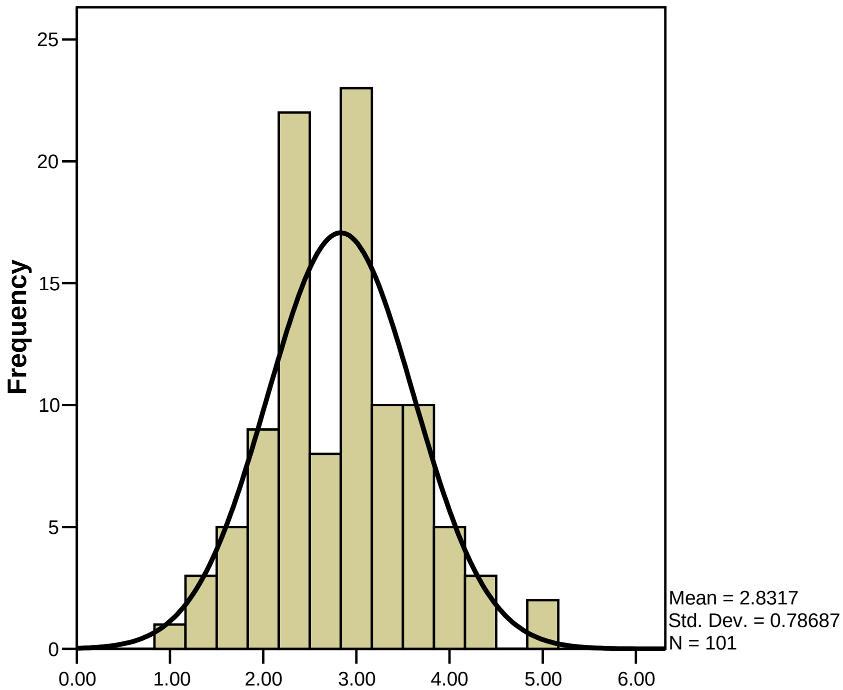


Figure 3-13. Media is the mean of three items: On the day of surgery, how often do people coordinate schedule changes using: (a) phone calls. (b) overhead announcements. (c) pager or beeper calls. Measured on a five point frequency Likert scale (1= Never, 2= Rarely, 3=Sometimes, 4=Usually, 5=Almost always).

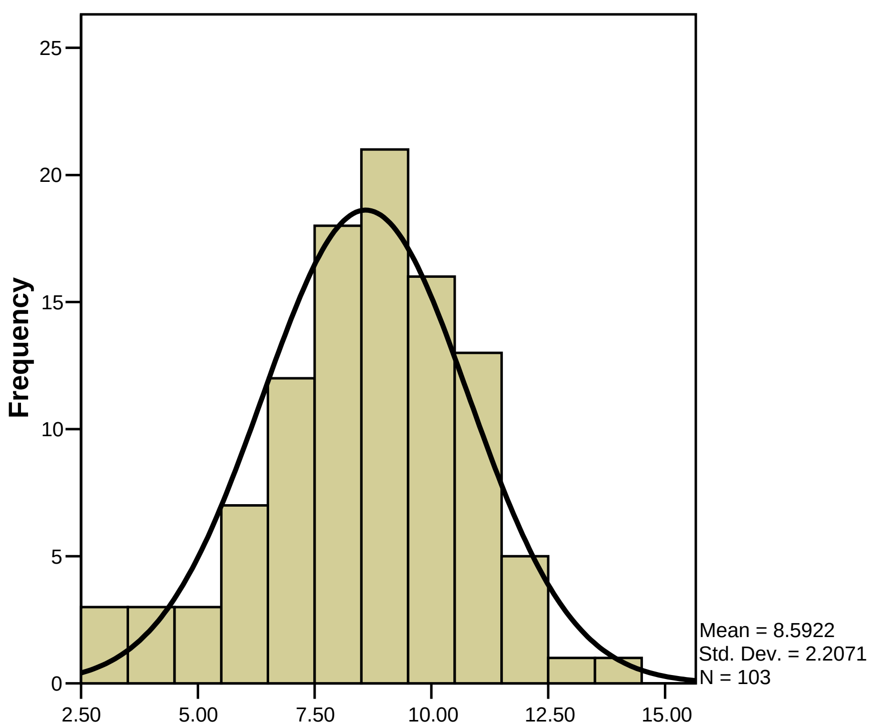


Figure 3-14. Information displayed is the sum of information types on the schedule board.

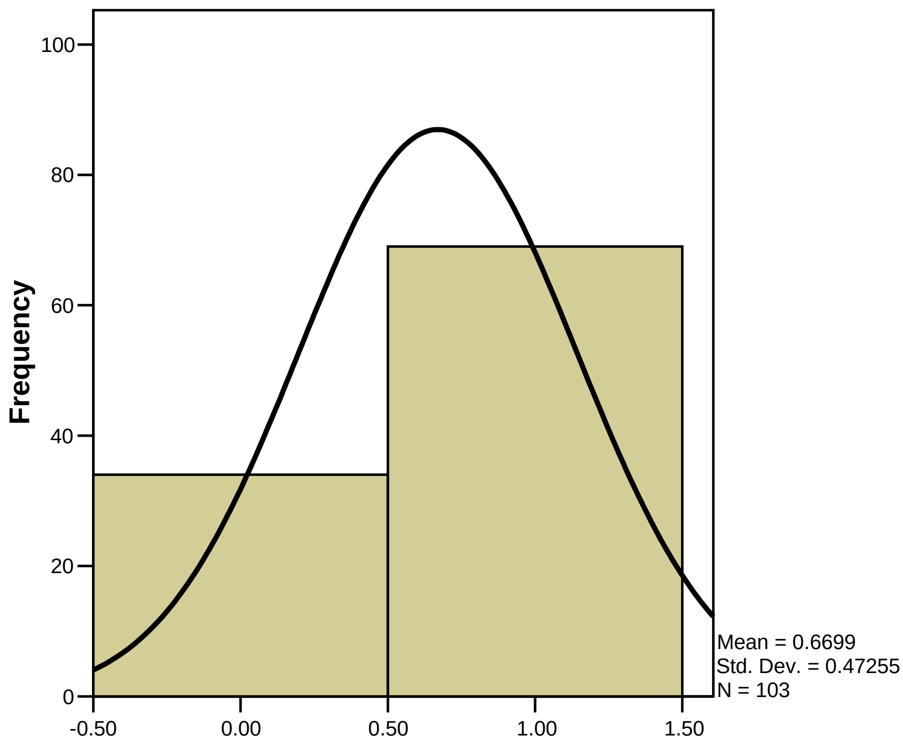


Figure 3-15. Posters around the schedule is measured as, how many papers, posters, or contact lists are posted near or around the schedule board." (Binary 0=Some papers, posters, or contact lists, 1= Very many).

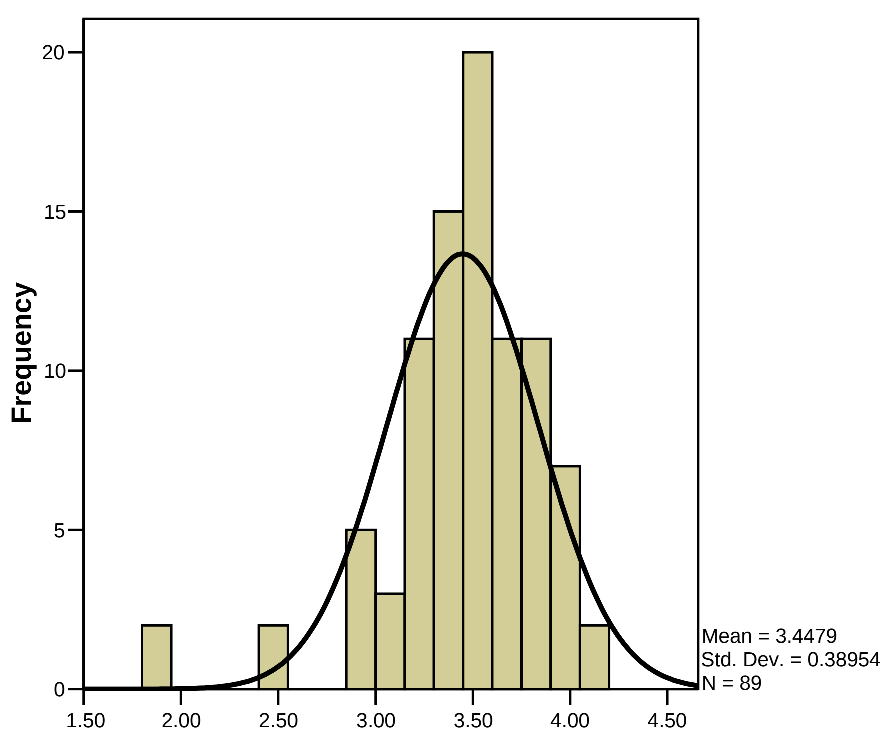


Figure 3-16. Log 10 schedule surface of the schedule board measured in square inches.

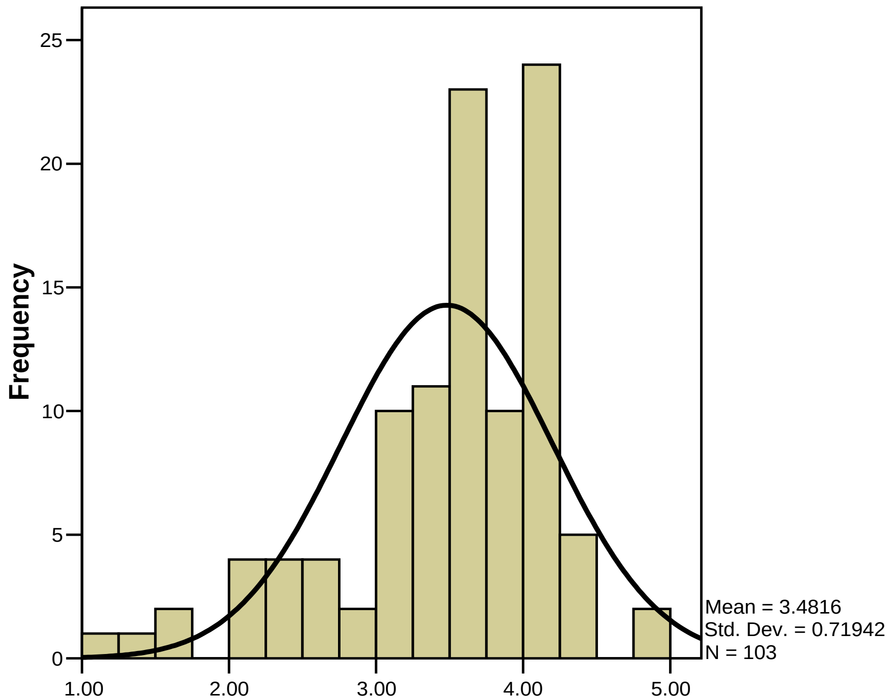
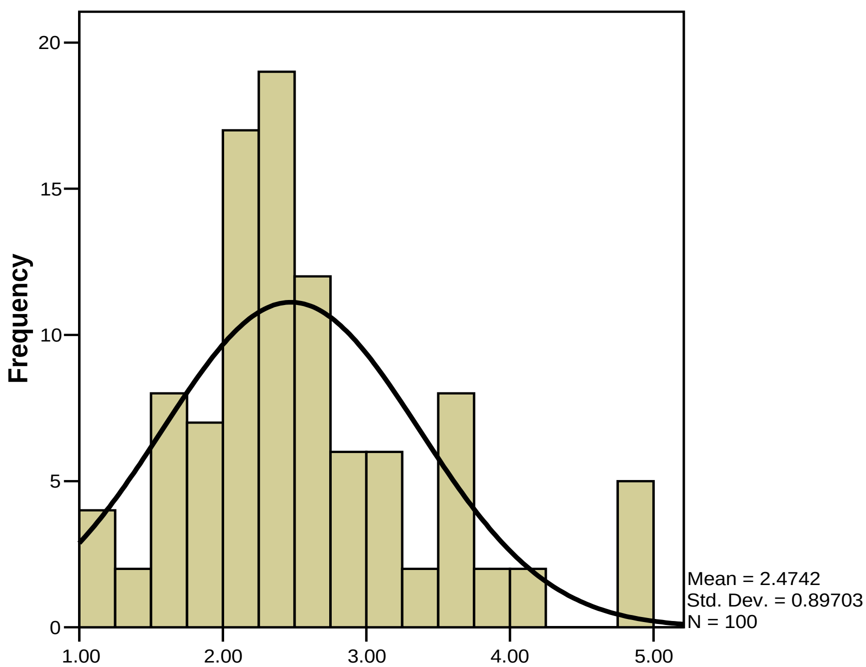


Figure 3-17. Congregating activity around the schedule board for charge nurse, control desk staff, OR nurses, charge anesthesiologist, anesthesia team members, surgeons and housekeeping staff. Measured with a five point Likert frequency scale (1= Never, 2= Rarely, 3=Sometimes, 4=Usually, 5=Almost always).



3-18. Updating schedule board for the nurse, charge anesthesiologist, OR nurses, anesthesia team members. Measured with a five point Likert frequency scale (1= Never, 2= Rarely, 3=Sometimes, 4=Usually, 5=Almost always).

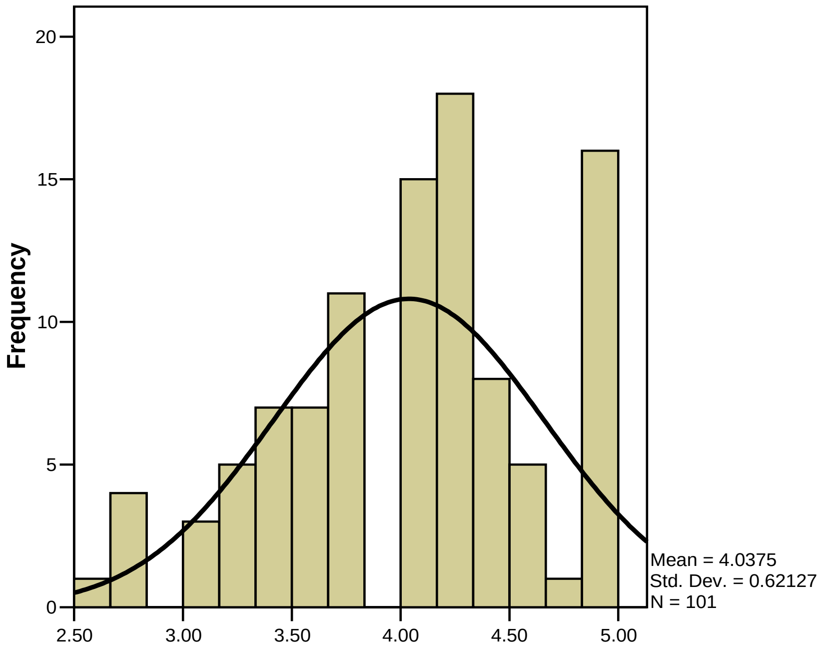


Figure 3-19. Coordination speed is the mean time to learn about schedule changes for the charge nurse, charge anesthesiologist, surgeon, OR nursing staff, anesthesia staff. Measured with a five point Likert frequency scale (1= More than one hour, 2= Within one hour, 3= Within thirty minutes, 4=Within a few minutes, 5=Almost immediately).

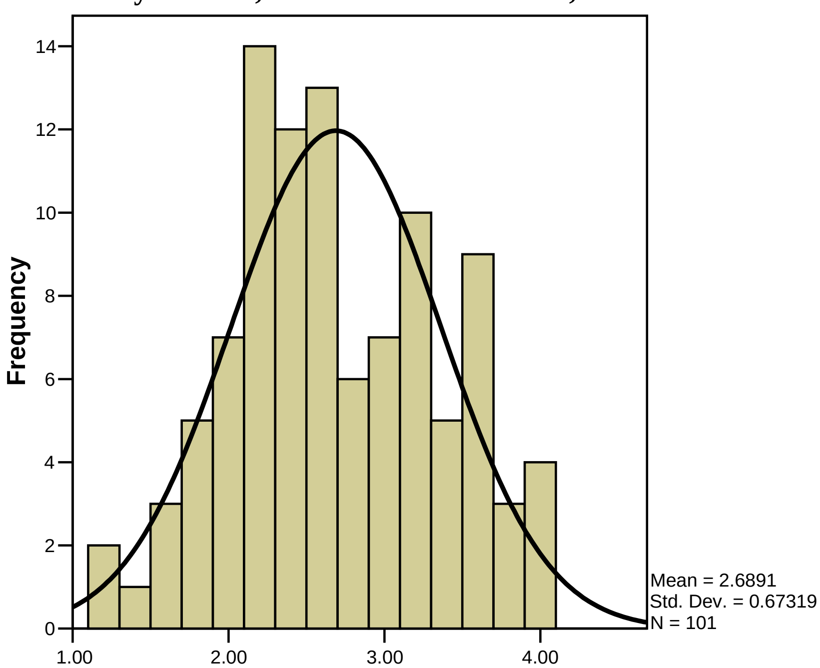


Figure 3-20. Coordination stress is the mean of five questions. (a) There are few schedule changes each day (inverted). (b) People adapt easily to OR schedule changes (inverted). (c) It takes little effort to update the schedule board (inverted). (d) People have to run around to learn about OR schedule changes. (e) OR schedule changes are stressful. Measured with a five point Likert scale (1= Strongly disagree to 5=Strongly agree).

Appendix 4: Detailed Regression Blocks

Statistical approach. I used hierarchical multiple regression to test each of the hypothesized relationships among input variables, coordination processes and coordination outcomes. One set of regressions was run for each of the four dependent measures: (a) congregating around the schedule board, (b) schedule board update activity, (c) coordination speed of schedule change updates to key staff members, and (d) coordination stress. I chose regression because there are no experimental conditions and chose a hierarchical form because that allows me to see how much each block of variables (where blocks are roughly equivalent to guidelines) contributes to the dependent measure.

For each analysis, the first block of variables entered was comprised of the two control variables, surgeries per room and log number of beds. Blocks 2-6 contain variables pertaining space adjacency, connectivity, interference, communication practices, and schedule board characteristics.

Block 1 (control variables): number of beds, number of surgeries per operating room.

Block 2 (space adjacency): visibility between schedule board area and control desk, and ease of updating the schedule board.

Block 3 (connectivity): distance to the sterile corridor and centrality with respect to the main corridor leading to the sterile corridor.

Block 4 (access area): presence of a traffic free area around schedule board; number of people who can comfortably gather around the schedule board; open access between the schedule board and sterile corridor; and how frequently people sit around the schedule board.

Block 5 (communication practices): Face-to-face conversation in hotspots, face-to-face conversation elsewhere, mediated communication.

Block 6 (schedule board): types of information posted on the schedule board, posters around the schedule board, schedule board size.

Additional blocks were added to specific regressions to test various components of the model (e.g., congregating was used as a predictor for coordination speed).

The order of the blocks was driven by the underlying theoretical framework, derived from the field studies, which specifies relationships between variables

Analysis of control variables. The field data from the Pennsylvania and Maryland field studies (Chapters 2 and 3), lead me to expect that: (a) the work setting (i.e., type of hospital, type of surgical suite, kind of surgical specialties present, and role assignments) and (b) the coordination load (i.e., number of cases per room, number of add-on cases per cases completed) would affect coordination behavior, independent of the architecture environment and information environment variables of interest.

To test this hypothesis, I ran regressions with work setting and coordination load as the independent variables and four dependent variables (congregating around the schedule board, update activity, coordination speed, and coordination stress). I found that entering all the control variables (i.e., type of hospital, type of surgical suite, kind of surgical specialties present, and role assignments) in a block did not result in significant regression models for coordination speed and update activity. Hospital size measured with hospital beds as an independent variable did result in a significant model for congregating activity as a dependent variable. Thus, to control for the work environment in the models that follow I entered two control variables: number of hospital beds (a proxy for hospital size) and surgeries per room (a proxy for coordination load).

Congregating activity. The first set of regression models had congregating around the schedule board as an outcome measure. Congregating around the schedule board was associated with four factors: visibility, use of mediated communication, face-to-face coordination of schedule changes in information hotspots, and hospital size. The visibility between the schedule board and control desk was associated with greater congregating activity around the schedule board. Greater frequency of mediated communication in the surgical suite (i.e., phone, pagers, and overhead announcements) was associated with greater congregating around the schedule board (figure 4.1). Updating frequency had a positive link to congregating activity. Face-to-face coordination regarding schedule changes in information hotspots (i.e., around the schedule board and the control desk) was associated with less congregating by the surgical suite staff around the schedule board. The number of patient beds in the hospital was negatively associated with congregating around the schedule board (Figure 4.1). See Table 4.1 for details for the unstandardized regression coefficients for the seven models tested.

Updating activity. The second set of models had update activity as the outcome measure. The first six blocks were as outlined above. In the seventh block, I placed update activity as an independent variable.

Updating frequency of the schedule board was not significantly associated with any of the input independent variables (i.e., the architecture environment, the information environment, and the work environment). Adjusted R^2 values were quite low for regression models including blocks 1-7. Adding congregating activity to the model significantly improved the R^2 ($F\ [1, 49] = 4.81$, $p < .05$), but the overall adjusted R^2 value remained low (Table 4.2)

Coordination speed. The third set of models used coordination speed—measured as the average amount of time it takes different roles to find out of schedule changes—as the outcome measure. The first six blocks of variables entered are the same as above. In the seventh model, I added two independent variables: congregating activity and update activity.

The coordination speed, how quickly people in the surgical suite found out about changes to the schedule, was associated with visibility in the architecture environment and update ease in the information environment. Visibility between the schedule board and control desk was associated with greater coordination speed of schedule changes. The presence of an easily updated schedule board was associated with greater coordination speed (Figure 4.1). See table 4.3 for the unstandardized regression coefficients for the seven models tested.

Coordination Stress. The fourth set of models had coordination stress as an outcome measure. The first seven models were the same as in the third set. In the eighth model, I added speed of coordination as an independent variable.

Coordination stress was associated with five factors: Three factors were associated with lower stress: the presence of a traffic-free area around the schedule board, greater coordination speed, and more types of information per operating room displayed on the schedule board. Coordination stress was positively associated with two factors: face-to-face interaction throughout the surgical suite to discuss schedule changes and the surface size of the schedule board (Figure 4.1). See table 4.4 for the unstandardized regression coefficients for the seven models tested.

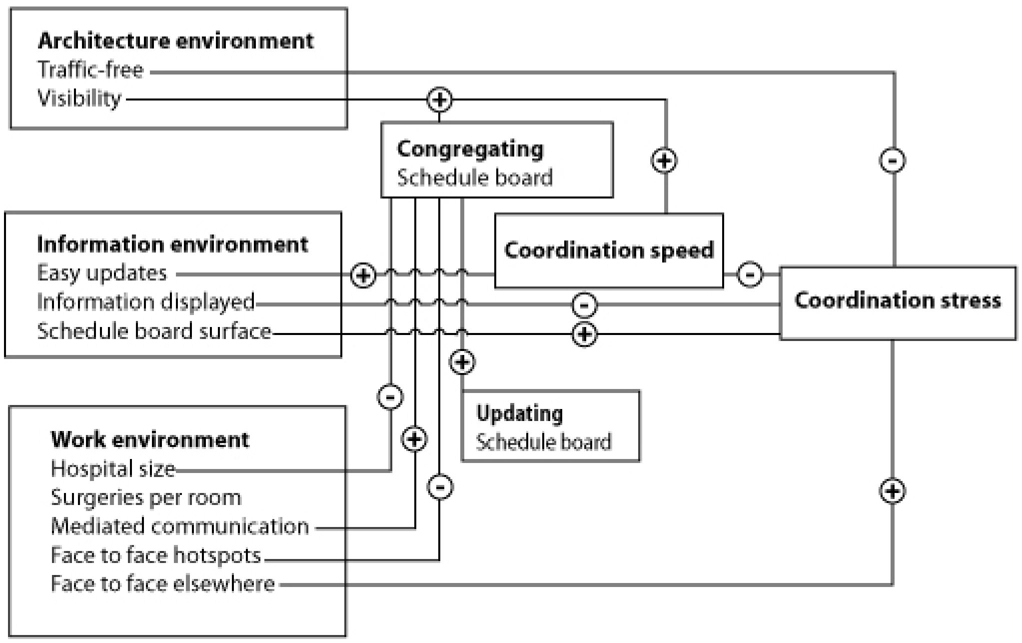


Figure 4-1. Diagram of the schedule board data. The positive and negative associations (p >.05) are mapped between a) architecture environment, b) information environment, c) work environment, d) congregating activity, e) coordination speed, and f) coordination stress.

Table 4-1. Hierarchical regressions predicting congregating activity around schedule board. The table shows unstandardized coefficients for each model followed by standard errors in parenthesis. Level of significance for the coefficients is reported as * p<.05, **p<.01; $^{+}$ p<.15. Table based on data from 104 surgical suites with schedule board and control desk.[1]

	1	2	3	4	5	6	7
Intercept	3.97** (.50)	2.81 (.58)	2.68** (.60)	2.33** (.60)	3.34** (.63)	2.48** (.86)	2.57** (.83)
Control							
Hospital beds	-.22 (.19)	-.18 (.17)	-.19 (.18)	-.24 (.17)	-.51** (.17)	-.47* (.18)	-.47** (.17)
Surgeries per room	.05 (.06)	.02 (.06)	.01 (.06)	.04 (.06)	.06 (.05)	.03 (.06)	.04 (.05)
Space adjacency							
Visibility		.55** (.17)	.57** (.18)	.48* (.18)	.50** (.16)	.48** (.17)	.45* (.17)
Easy updates		.74** (.31)	.73* (.31)	.44 (.32)	.31 (.30)	.31 (.31)	.36 (.30)
Connectivity							
log 10 Distance sterile corridor			.05 (.13)	.04 (.13)	.20 (.13)	.18 (.13)	.15 (.12)
Centrality			.14 (.17)	.11 (.16)	.12 (.14)	.11 (.14)	.12 (.14)
Access area							
Traffic free schedule				-.01 (.06)	-.01 (.05)	-.01 (.05)	-.02 (.05)
Gathering schedule				.13* (.05)	.12* (.05)	.09 (.05)	.08 (.05)
Barrier free schedule				.06 (.14)	.08 (.13)	.08 (.13)	.06 (.13)
Sitting around schedule board				.10* (.05)	.05 (.05)	.04 (.05)	.03 (.05)
Communication practice							
Face-to-face hotspots					-.12 (.10)	-.14 (.11)	-.11 (.10)
Face-to-face elsewhere					-.22**(.08)	-.18*(.08)	-.22**(.08)
Media					.29** (.09)	.27** (.09)	.26** (.09)
Schedule board							
log Schedule surface						.25 (.19)	.19 (.18)
Information displayed						.02 (.03)	.00 (.03)
Posters schedule board						.01 (.13)	-.02 (.12)
Coordination Processes							
Updates schedule							.14* (.06)
R^2 (R^2 adjusted)	.04 (.01)	.22 (.17)	.23 (.15)	.37 (.26)	.53 (.41)	.55 (.40)	.59 (.45)
F full model	1.22	4.3**	2.94**	3.27**	4.56**	3.80**	4.13**
Degrees of Freedom	2, 64	4, 62	6, 60	10, 56	13, 53	16, 50	17, 49
R^2 Change	0.04	0.18	0.01	0.14	0.16	0.02	0.04
F Change	1.22	7.15**	0.38	3.14**	5.96**	0.77	4.81*
DF Change	2, 64	2, 62	2, 60	4, 56	3, 53	3, 50	1, 49

[1] See Table 5-4 (Chapter 5) for complete variable definitions.

Table 4-2. Hierarchical regressions predicting schedule board update activity. The table shows unstandardized coefficients for each model and standard errors in parenthesis. Level of significance is reported as * p<.05, **p<.01; $^{+}$ p<.15. The table data are based on 104 surgical suites with schedule board and control desk. [1]

	1	2	3	4	5	6	7
Intercept	2.32^{**} (.81)	2.01^{*} (1.01)	2.00 (1.05)	1.61 (1.13)	1.09 (1.36)	-.60 (1.81)	-2.17 (1.89)
Control							
Hospital beds	.16 (.30)	.14 (.30)	.09 (.31)	.02 (.33)	-.06 (.37)	-.03 (.38)	.27 (.39)
Surgeries per room	-.03 (.09)	-.03 (.10)	-.01 (.10)	-.01 (.11)	.00 (.11)	-.07 (.12)	-.09 (.11)
Space adjacency							
Visibility		.44 (.30)	.44 (.31)	.37 (.35)	.37 (.35)	.21 (.37)	-.09 (.38)
Easy updates		-.02 (.54)	-.05 (.55)	-.34 (.61)	-.24 (.65)	-.31 (.65)	-.51 (.63)
Connectivity							
log 10 Distance sterile corridor			.18 (.23)	.21 (.25)	.19 (.27)	.16 (.27)	.05 (.27)
Centrality			-.10 (.29)	-.11 (.30)	-.09 (.31)	-.07 (.31)	-.14 (.30)
Access area							
Traffic free schedule				.09 (.11)	.09 (.11)	.13 (.11)	.13 (.11)
Gathering schedule				.09 (.10)	.11 (.10)	.07 (.10)	.01 (.10)
Barrier free schedule				.02 (.26)	.10 (.27)	.17 (.28)	.12 (.27)
Sitting around schedule board				.07 (.09)	.07 (.10)	.02 (.10)	.00 (.10)
Communication practice							
Face-to-face hotspots					-.12 (.23)	-.17 (.22)	-.08 (.22)
Face-to-face elsewhere					.17 (.16)	.25 (.17)	$.36^{*}$ (.17)
Media					.14 (.19)	.11 (.20)	-.06 (.20)
Schedule board							
log Schedule board surface						.37 (.39)	.21 (.39)
Information displayed						.10 (.06)	.09 (.06)
Posters schedule board						.17 (.27)	.17 (.26)
Coordination processes							
Congregating							$.63^{*}$ (.29)
R^2 (R^2 adjusted)	.01 (-.02)	.04 (-.02)	.05 (-.04)	.09 (-.07)	.12 (-.10)	.19 (-.07)	.26 (.01)
F full model	0.24	0.65	0.58	0.54	0.55	0.74	1.03
Degrees of Freedom	2, 64	4, 62	6, 60	10, 56	13, 53	16, 50	17, 49
R^2 Change	.01	.03	.01	.03	.03	.07	.07
F Change	.24	1.07	.45	.52	.62	1.47	4.81^{*}
DF Change	2, 64	2, 62	2, 60	4, 56	3, 53	3, 50	1, 49

[1] **See Table 5-4 (Chapter 5) for complete variable definitions.**

Table 4-3. Hierarchical regressions predicting coordination speed. The table shows unstandardized coefficients and standard errors in parenthesis. Level of significance for the coefficients is reported as * p<.05, **p<.01; $^{+}$ p<.15. The data used is from 104 surgical suites with schedule board and control desk. [1]

	1	2	3	4	5	6	7
Intercept	4.08**	2.93**	3.11**	3.33**	3.47**	2.98*	2.94*
	(.58)	(.67)	(.68)	(.69)	(.93)	(1.11)	(1.24)
Control	-.08	-.04	-.09	-.23	-.27	-.21	-.20
Hospital Beds	(.21)	(.20)	(.20)	(.20)	(.20)	(.23)	(.25)
Surgeries per room	.03	.01	.04	.00	-.02	-.01	-.01
	(.07)	(.06)	(.06)	(.07)	(.07)	(.07)	(.07)
Space adjacency		.57**	.54**	.45*	.31	.29	.27
Visibility		(.20)	(.20)	(.21)	(.22)	(.23)	(.25)
Easy updates		.71*	.70*	.67	.58	.50	.50
		(.36)	(.35)	(.37)	(.37)	(.40)	(.42)
Connectivity							
log 10 Distance			.11	.24	.25	.18	.18
sterile corridor			(.15)	(.15)	(.15)	(.17)	(.17)
Centrality			-.32	-.30	-.26	-.28	-.28
			(.19)	(.19)	(.18)	(.19)	(.19)
Access area				.05	.08	.08	.08
Traffic free schedule				(.06)	(.07)	(.07)	(.07)
Gathering schedule				.07	.08	.08	.08
				(.06)	(.06)	(.06)	(.07)
Barrier free schedule				.23	.31	.30	.30
				(.16)	(.16)	(.17)	(.17)
Sitting around				-.09	-.12*	-.12	-.12
schedule board				(.06)	(.06)	(.06)	(.06)
Schedule board					-.17	-.15	-.16
lob Schedule surface					(.23)	(.24)	(.25)
Information displayed					.06	.06	.06
					(.04)	(.04)	(.04)
Posters around					.23	.23	.23
schedule board					(.16)	(.17)	(.17)
Communication practice						.13	.14
Face-to-face hotspots						(.14)	(.14)
Face-to-face elsewhere						.03	.03
						(.10)	(.12)
Media						-.05	-.06
						(.12)	(.13)
Coordination processes							.02
Congregating							(.20)
Update							.02
							(.86)
R^2 (R^2 adjusted)	.01 (-.02)	.16 (.10)	.21 (.14)	.32 (.19)	.38 (.23)	.39 (.20)	.40 (.17)
F full model	.24	2.87*	2.72*	2.58*	2.49*	2.04*	1.74*
Degrees of Freedom	2, 64	4, 62	6, 60	10, 56	13, 53	16, 50	18, 48
R^2 Change	.01	.15	.06	.10	.06	.02	.00
F Change	.24	5.47**	2.2^{+}	2.07^{+}	1.80	.44	.03
DF Change	2, 64	2, 62	2, 60	4, 56	3, 53	3, 50	2, 48

[1] **See Table 5-4 (Chapter 5) for complete variable definitions.**

Table 4-4. Hierarchical regressions predicting coordination stress. The table reports unstandardized coefficients for each model, standard errors are in parenthesis. Level of significance for the coefficients is reported as * p<.05, **p<.01; +p<.15. The data used is from 104 surgical suites with schedule board and control desk. [1]

	1	2	3	4	5	6	7	8
Intercept	3.64** (.58)	4.07** (.73)	3.75** (.74)	3.64** (.71)	2.85** (.90)	2.05* (1.03)	1.84 (1.15)	3.02** (1.10)
Control								
Hospital beds	-.26 (.21)	-.30 (.22)	-.31 (.22)	-.15 (.21)	-.04 (.19)	-.08 (.21)	-.03 (.23)	-.11 (.21)
Surgeries per room	-.07 (.07)	-.06 (.07)	-.08 (.07)	-.01 (.07)	-.01 (.07)	-.01 (.07)	-.01 (.07)	-.02 (.06)
Space adjacency								
Visibility		.02 (.22)	.07 (.22)	.13 (.22)	.20 (.22)	.20 (.21)	.15 (.23)	.26 (.21)
Easy updates		-.45 (.39)	-.47 (.39)	-.41 (.38)	-.45 (.36)	-.29 (.37)	-.31 (.38)	-.10 (.35)
Connectivity								
log 10 Distance sterile corridor			.10 (.16)	-.07 (.16)	-.10 (.15)	-.12 (.15)	-.15 (.16)	-.07 (.15)
Centrality			.38 (.2)	.34 (.19)	.26 (.18)	.28 (.17)	.27 (.18)	.16 (.17)
Access area								
Traffic free schedule				-.17* (.07)	-.17* (.06)	-.17** (.06)	-.18** (.06)	-.14* (.06)
Gathering schedule				-.04 (.06)	-.08 (.06)	-.07 (.06)	-.09 (.06)	-.05 (.06)
Barrier free schedule				-.18 (.16)	-.24 (.16)	-.17 (.16)	-.18 (.16)	-.06 (.15)
Sitting around schedule board				.11 (.06)	.12* (.06)	.13* (.06)	.12* (.06)	.07 (.06)
Schedule board								
log Schedule surface					.46* (.22)	.54* (.23)	.50* (.23)	.44* (.21)
Information displayed					-.10** .03)	-.09* (.03)	-.10* (.04)	-.07* (.03)
Posters schedule board					.01 (.16)	-.02 (.15)	-.03 (.16)	.06 (.15)
Communication practice								
Face-to-face hotspots						-.16 (.13)	-.14 (.13)	-.08 (.12)
Face-to-face elsewhere						.20* (.10)	.20 (.11)	.22* (.10)
Media						.09 (.11)	.06 (.12)	.04 (.11)
Coordination processes								
Congregating activity							.10 (.18)	.10 (.16)
Updates activity							.05 (.58)	.05 (.08)
Coordination speed								-.40** (.12)
R^2 (R^2 adjusted)	.03 (.00)	.05 (-.01)	.11 (.02)	.31 (.19)	.44 (.30)	.50 (.34)	.51 (.32)	.60 (.44)
F full model	1.13	.9	1.19	2.51*	3.20**	3.10**	2.74**	3.72**
Degrees of Freedom	2,64	4,62	6,60	10,56	13,53	16,50	18,48	19,47
R^2 Change	.03	.02	.05	.20	.13	.06	.01	.09
F Change	1.13	.68	1.73	4.11**	4.1**	1.94	.42	11.04**
DF Change	2,64	2,62	2,60	4,56	3,53	3,50	2,48	1,47

Appendix 5: Control Desk and Schedule Board Models

I collected survey data on the schedule board, control desk, and the relationship between the schedule board and control desk. Next, I describe models of control desk data analyzed alone and schedule board and control desk data analyzed together. I developed the independent measures for the schedule board and control desk accordingly. The dependent measures regarding update activity to the schedule board, coordination speed, and coordination stress are the same for all analyses. The congregating activity is specific to what is being studied (i.e., congregating around the schedule board, congregating around the control desk, or congregating around the schedule board and the control desk.)

Control desk only. In the control desk data, I found three significant links to congregating around the control desk: distance between the control desk and sterile corridor, sitting around the control desk, and frequency of updates to the schedule board. The closer the sterile corridor was to the control desk, the greater the congregating activity. The more frequently people sat around the control desk, the greater the congregating activity of staff around the control desk. The frequency of updating the schedule board was positively associated with greater congregating around the control desk (Figure 5-1).

As noted previously for the schedule board data, coordination speed was positively associated with visibility between the schedule board and control desk. Likewise, easy updates was positively associated with coordination speed. As with the schedule board data, coordination stress had a negative relationship to coordination speed. In summary, the characteristics of the architecture environment around the control desk were associated mostly with congregating around the control desk (Figure 5-1). Tables 5.1-5.4 show the results for models predicting congregating activity, updating activity, coordination speed, and coordination stress.

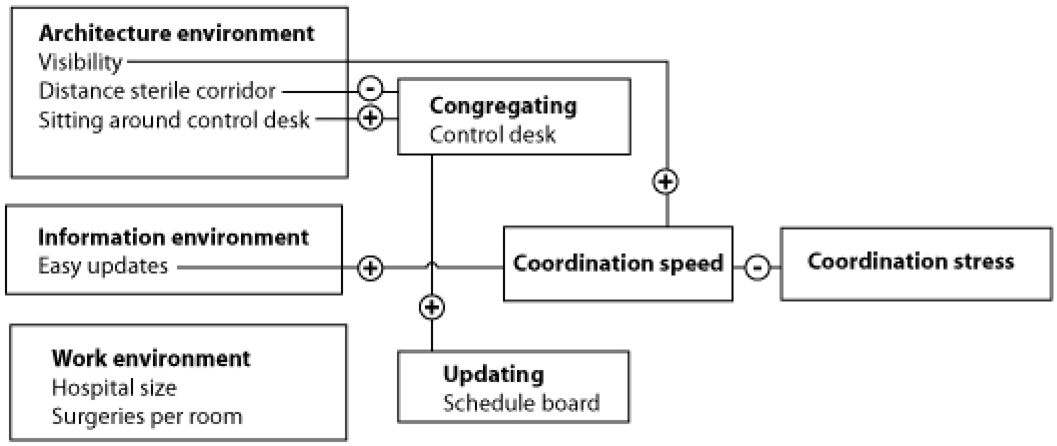


Figure 5-1. Diagram of the control desk data modeled alone. The positive and negative associations (p >.05) are mapped between a) architecture environment, b) information environment, c) work environment, d) congregating activity, e) coordination speed, and f) coordination stress.

Schedule board and control desk together. In the combined data for the schedule board and the control desk, I found two items were positively associated with congregating around the schedule board and the control desk: first, visibility between the schedule board and control desk, and second, the updating activity frequency of the schedule board. Coordination speed was positively associated with easy updates. Coordination stress was negatively associated with three items: traffic free areas around the schedule board and control desk, coordination speed, and face-to-face discussion of schedule changes at hotspots (i.e., around the schedule board and the control desk). Face-to-face discussion about schedule changes elsewhere in the surgical suite (i.e., the hallway, break rooms, cafeteria, etc.) was associated with increased coordination stress. Posters placed around the schedule board and control desk were positively associated with coordination stress as well (Figure 5.2). Tables 5.5-5.8 show the results for models predicting congregating activity, updating activity, coordination speed, and coordination stress.

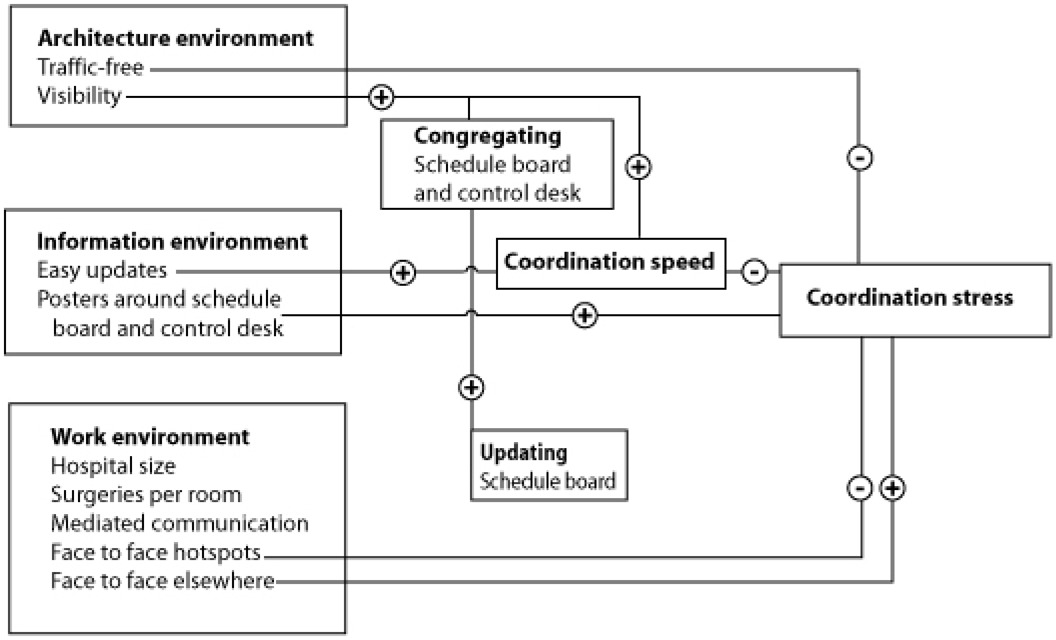


Figure 5-2. Diagram of the schedule board and control desk data modeled together. The positive and negative associations (p >.05) are mapped between a) architecture environment, b) information environment, c) work environment, d) congregating activity, e) coordination speed, and f) coordination stress.

Exploratory analysis. I discuss the exploratory analysis done with stepwise regression in three parts. First, I present the results from models with the schedule board only. Second, I present the results from the models for the control desk only. Third, I present the results from models that consider the schedule board and control desk together. In the previous section, I entered all the variables for each model to the regression at once.

Next, I describe a stepwise hierarchical multiple regression. With a stepwise regression function, the independent variables are added one at a time to the regression equation; the stepwise regression function removes the variables in other steps that do not contribute significantly any more. Thus, models in this section highlight the independent variables that significantly contribute to the regression only. I used the same blocks of variables described previously for each step. The control variables were entered first, and the other blocks as a series of stepwise regressions.

Schedule board alone. Figure 5-1 shows the significant relationships in the stepwise hierarchical multiple regression for the schedule board alone. The main differences with the model in figure 1 include: (a) gathering size around the schedule board is positively associated with congregating frequency of staff around the schedule board. (b) Face-to-face discussion of schedule changes elsewhere in the surgical suite is negatively associated with congregating around the schedule board. (c) In the previous model illustrated in figure 1, face-to-face elsewhere was negatively associated with coordination stress; (d) face-to-face discussion at hotspots was negatively associated with congregating at the schedule board.

Control desk alone. Figure 5-2 shows the significant relationships resulting from a stepwise hierarchical multiple regression. The model below differs in three ways from the previous model for the control desk alone in figure 2: (a) visibility between the schedule board and control desk associated with congregating at the control desk and the presence of information around the control desk associated with negatively with coordination speed and positively with coordination stress. Congregating at the control desk is positively associated with three factors: (a) visibility, (b) frequency with which people sit around the control desk, (c) updating of the schedule board, and negatively associated with the distance between the control desk and the sterile corridor. Coordination speed in the model below is associated with three independent variables: positively associated with (a) visibility and (b) easy updates of the schedule board and negatively associated with (c) the presence of information around the control desk. Coordination speed has a negative relation to coordination stress. Information around the control desk is positively associated with coordination stress.

Schedule board and control desk together. Figure 5-3 shows the significant relationships for schedule board and control desk together. There are four fewer associations than in figure 3: (a) visibility to coordination speed, (b) posters around schedule board and control desk to coordination stress, (c) face-to-face coordination at hotspots, and (d) face-to-face coordination elsewhere to coordination stress. However, a positive connection between congregating and coordination speed is present below.

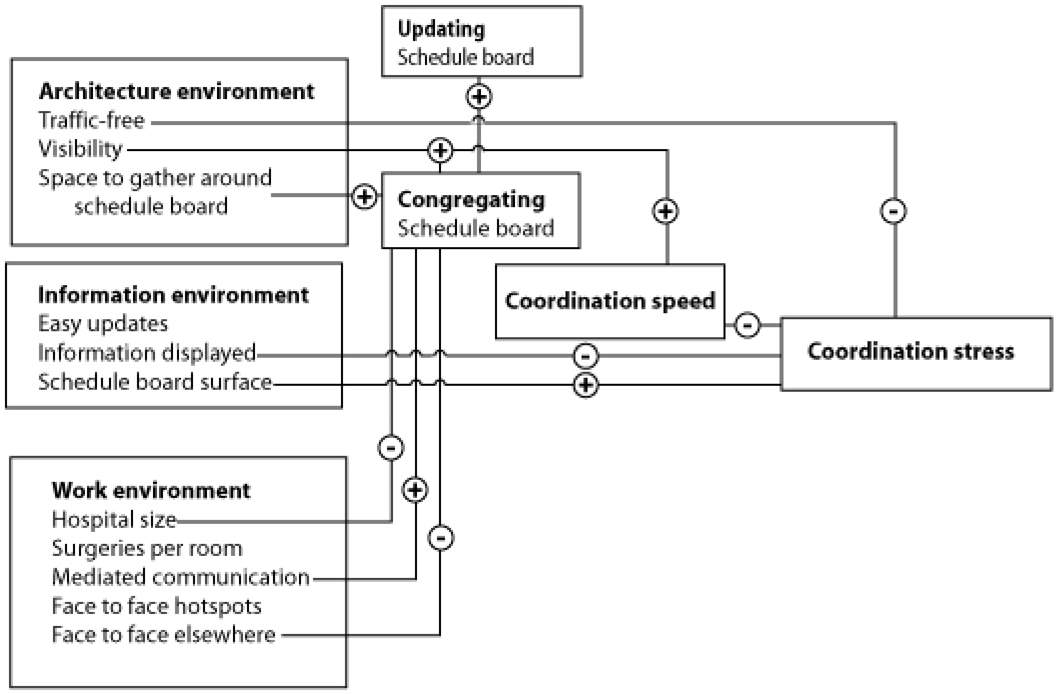


Figure 5-1. Diagram of the schedule board data modeled alone with a stepwise regression. The positive and negative associations (p >.05) are mapped between a) architecture environment, b) information environment, c) work environment, d) congregating activity, e) coordination speed, and f) coordination stress.

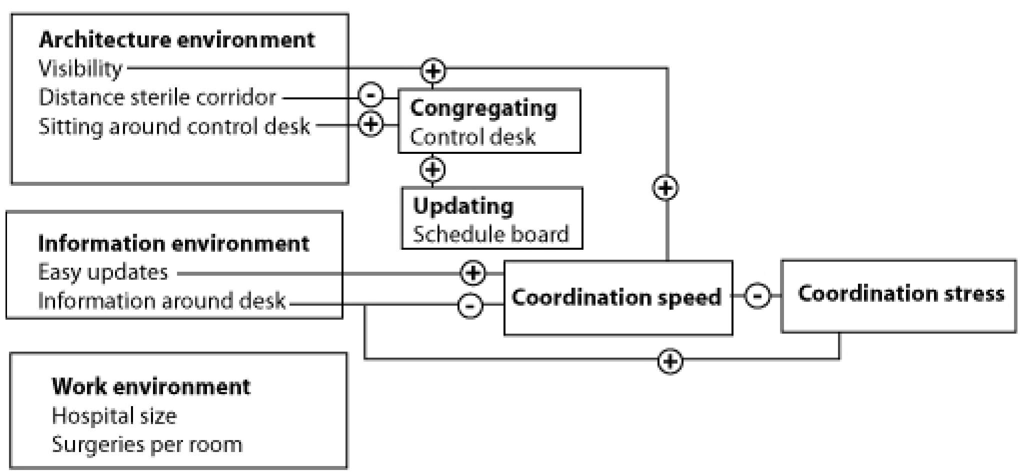


Figure 5-2. Diagram of the control desk data modeled alone. The positive and negative associations (p >.05) are mapped between a) architecture environment, b) information environment, c) work environment, d) congregating activity, e) coordination speed, and f) coordination stress.

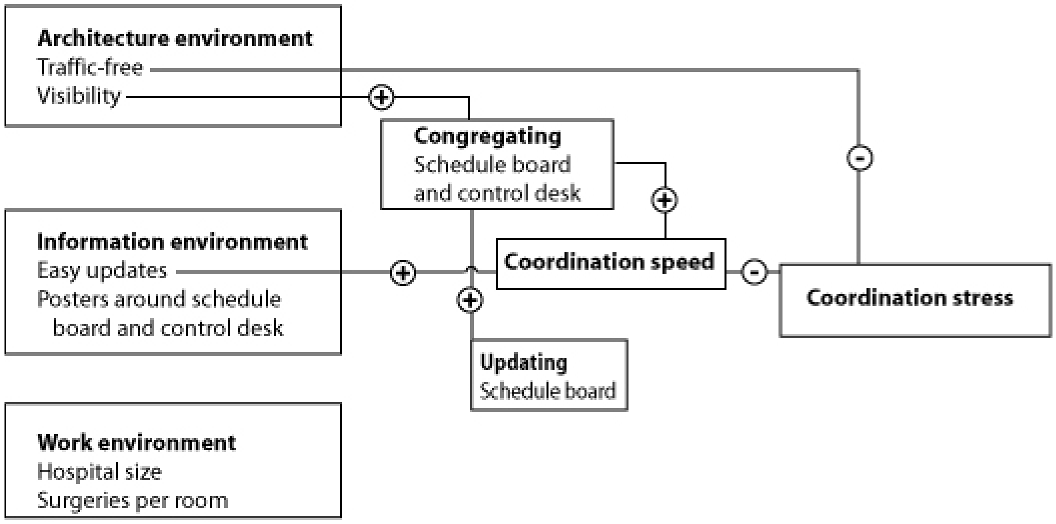


Figure 5-3. Diagram of the schedule board and control desk data modeled together. The positive and negative associations (p >.05) are mapped between a) architecture environment, b) information environment, c) work environment, d) congregating activity, e) coordination speed, and f) coordination stress.

Table 5-1. Hierarchical regressions predicting congregating activity around the control desk. Unstandardized coefficients for control desk data modeled alone. Significance levels expressed as * p< .05, and ** p<.01; $^{+}$ p<.15.[1]

	1	2	3	4	5	6	7
Intercept	2.76^{**} (.48)	2.42^{**} (.65)	2.78^{**} (.70)	2.28^{**} (.81)	1.81^{*} (.91)	1.82 (.97)	1.59 (.95)
Control							
Hospital beds	.19 (.18)	.15 (.18)	.13 (.18)	.21 (.18)	.17 (.19)	.13 (.20)	.14 (.19)
Surgeries per room	.09 (.06)	.07 (.06)	.05 (.06)	.07 (.06)	.08 (.06)	.08 (.06)	.09 (.06)
Architecture environment							
Space adjacency Visibility		$.39^{*}$ (.17)	.32 (.17)	.31 (.17)	.34 (.18)	$.35^{*}$ (.18)	.30 (.17)
Easy updates		.20 (.44)	.16 (.43)	.14 (.42)	.13 (.43)	.13 (.43)	.08 (.42)
Connectivity log Distance control desk sterile corridor			-.24 (.16)	$-.31^{*}$ (.16)	-.28 (.17)	-.32 (.17)	$-.33^{*}$ (.17)
Centrality of control desk			.14 (.17)	.17 (.17)	.20 (.17)	.15 (.18)	.15 (.17)
Access areas Traffic free control desk				-.07 (.06)	-.05 (.06)	-.06 (.06)	-.05 (.06)
Gathering control desk				-.06 (.06)	-.06 (.06)	-.05 (.06)	-.06 (.05)
Barrier-free control desk				.02 (.15)	.05 (.15)	.02 (.16)	.02 (.15)
Sitting around control desk				$.19^{*}$ (.08)	$.17^{*}$ (.09)	$.17^{*}$ (.09)	$.16^{*}$ (.08)
Information environment							
Communication Practice Media					.09 (.11)	.10 (.11)	.06 (.11)
Face-to-face hotspots					-.03 (.14)	-.01 (.14)	.00 (.13)
Face-to-face elsewhere					.10 (.10)	.09 (.10)	.07 (.10)
Control desk Information posted around control desk						-.16 (.27)	-.13 (.26)
Counters control desk							.08 (.08)
Coordination processes Average updates schedule							$.18^{*}$ (.08)
R^2 (R^2 adjusted)	.04 (.02)	.11 (.06)	.17 (.09)	.26 (.14)	.28 (.13)	.30 (.13)	.36 (.18)
F full model	1.6	2.15^{+}	2.29^{*}	2.27^{*}	1.88^{*}	1.73^{+}	2.03^{*}
Degrees of Freedom	2, 73	4, 71	6, 69	10, 65	13, 62	15, 60	16, 59
R^2 Change	.04	.07	.06	.09	.02	.02	.05
F Change	1.6	2.64^{+}	2.4^{+}	2.04^{+}	.68	.85	4.82^{*}
DF Change	2, 73	2, 71	2, 69	4, 65	3, 62	2, 60	1, 59

[1] See Table 5-4 (Chapter 5) for complete variable definitions.

Table 5-2. Hierarchical regressions predicting updating activity around the control desk. Unstandardized coefficients for control desk data modeled alone. Significance levels expressed as * p< .05, and ** p<.01; $^{+}$ p<.15.[1]

	1	2	3	4	5	6	7
Intercept	2.51** (.66)	2.14* (.93)	2.08* (1.02)	2.03 (1.26)	1.30 (1.41)	1.32 (1.51)	.54 (1.51)
Control							
Hospital beds	.09 (.25)	.07 (.26)	.07 (.26)	.09 (.28)	-.02 (.30)	-.05 (.30)	-.11 (.30)
Surgeries per room	-.06 (.08)	-.07 (.08)	-.07 (.08)	-.06 (.09)	-.03 (.10)	-.03 (.10)	-.06 (.10)
Architecture environment							
Space adjacency							
Visibility		.24 (.24)	.25 (.25)	.24 (.26)	.29 (.27)	.31 (.28)	.16 (.28)
Easy updates		.29 (.62)	.29 (.63)	.28 (.65)	.26 (.66)	.25 (.67)	.20 (.65)
Connectivity							
log distance control desk sterile corridor			.04 (.24)	.00 (.25)	.07 (.26)	.02 (.27)	.16 (.27)
Centrality control desk			-.01 (.25)	.01 (.26)	.06 (.27)	.01 (.28)	-.06 (.27)
Access area							
Traffic free control desk				-.06 (.09)	-.04 (.09)	-.04 (.09)	-.02 (.09)
Gathering control desk				.00 (.09)	.01 (.09)	.01 (.09)	.04 (.09)
Barrier free control desk				-.05 (.23)	.00 (.24)	-.03 (.24)	-.04 (.24)
Sitting around control desk				.07 (.13)	.04 (.13)	.03 (.13)	-.04 (.13)
Information environment							
Communication practice							
Media					.20 (.17)	.22 (.18)	.17 (.17)
Face-to-face hotspots					-.07 (.21)	-.05 (.21)	-.05 (.21)
Face-to-face elsewhere					.12 (.15)	.12 (.16)	.08 (.15)
Control desk							
Information posted around control desk						-.17 (.42)	-.10 (.41)
Counters control desk						.54 (.51)	.06 (.13)
Coordination processes							
Congregating activity control desk							.43* (.19)
R^2 (R^2 adjusted)	.01 (-.02)	.02 (-.03)	.02 (-.06)	.04 (-.11)	.08 (-.12)	.09 (-.14)	.16 (-.07)
F full model	.34	.44	.29	.26	.40	.39	.69
Degrees of Freedom	2, 73	4, 71	6, 69	10, 65	13, 62	15, 60	16, 59
R^2 Change	.01	.01	.00	.01	.04	.01	.07
F Change	.34	.54	.02	.24	.84	.38	4.82*
DF Change	2, 73	2, 71	2, 69	4, 65	3, 62	2, 60	1, 59

[1] **See Table 5-4 (Chapter 5) for complete variable definitions.**

Table 5-3. Hierarchical regressions predicting coordination speed around the control desk. Unstandardized coefficients for control desk data modeled alone. Significance levels expressed as * p< .05, and ** p<.01; + p<.15. [1]

	1	2	3	4	5	6	7
Intercept	4.13** (.47)	2.87** (.62)	3.04** (.66)	3.07** (.78)	3.05** (.89)	3.77** (.92)	3.37** (.93)
Control							
Hospital beds	-.06 (.18)	-.06 (.17)	-.05 (.17)	-.07 (.17)	-.09 (.19)	-.12 (.18)	-.14 (.18)
Surgeries per room	.01 (.06)	-.02 (.05)	-.02 (.05)	.01 (.05)	.02 (.06)	.02 (.06)	.01 (.06)
Architecture environment							
Space adjacency							
Visibility		.35* (.16)	.39* (.16)	.36* (.16)	.34* (.17)	.32 (.17)	.24 (.17)
Easy updates		1.12** (.41)	1.20** (.41)	1.24** (.40)	1.21** (.42)	1.12** (.41)	1.08* (.40)
Connectivity							
log distance control desk sterile corridor			-.08 (.16)	-.07 (.15)	-.06 (.16)	-.13 (.16)	-.07 (.17)
Centrality control desk			-.30 (.16)	-.36* (.16)	-.36* (.17)	-.37* (.17)	-.40* (.17)
Access area							
Traffic free control desk				-.07 (.06)	-.07 (.06)	-.10 (.06)	-.09 (.06)
Gathering control desk				-.04 (.05)	-.04 (.05)	-.03 (.05)	-.03 (.05)
Barrier free control desk				.34* (.14)	.34* (.15)	.27 (.15)	.27 (.15)
Sitting around control desk				.04 (.08)	.03 (.08)	.03 (.08)	.00 (.08)
Information environment							
Communication practice							
Media					.01 (.11)	.02 (.11)	-.01 (.11)
Face-to-face hotspots					.05 (.13)	.09 (.13)	.10 (.13)
Face-to-face elsewhere					-.04 (.10)	-.02 (.09)	-.04 (.09)
Control desk							
Information posted around control desk						-.59* (.26)	-.55* (.25)
Counters control desk						-.03 (.08)	-.05 (.08)
Coordination processes							
Congregating activity control desk							.16 (.12)
Updating schedule board							.08 (.08)
R^2 (R^2 adjusted)	.00 (-.03)	.14 (.09)	.18 (.11)	.27 (.15)	.27 (.12)	.33 (.17)	.37 (.19)
F full model	.08	2.81*	2.51*	2.38*	1.77+	1.99*	2.02*
Degrees of Freedom	2, 73	4, 71	6, 69	10, 65	13, 62	15, 60	17, 58
R^2 Change	.00	.13	.04	.09	.00	.06	.04
F Change	.08	5.53*	1.79	1.96+	.09	2.77+	1.82
DF Change	2, 73	2, 71	2, 69	4, 65	3, 62	2, 60	2, 58

[1] **See Table 5-4 (Chapter 5) for complete variable definitions.**

Table 5-4. Hierarchical regressions predicting coordination stress around the control desk. Unstandardized coefficients for control desk data modeled alone. Significance levels expressed as * p< .05, and ** p<.01; $^{+}$ p<.15. [1]

	1	2	3	4	5	6	7	8
Intercept	3.18	4.08**	3.99**	4.42**	3.97**	3.42**	3.54**	5.1**
	(.49)	(.68)	(.74)	(.89)	(.97)	(1.01)	(1.05)	(1.07)
Control								
Hospital beds	-.13	-.17	-.16	-.20	-.26	-.20	-.19	-.25
	(.19)	(.19)	(.19)	(.19)	(.21)	(.20)	(.21)	(.19)
Surgeries per room	-.03	-.02	-.02	-.01	.00	.00	.01	.01
	(.06)	(.06)	(.06)	(.06)	(.07)	(.07)	(.07)	(.06)
Architecture environment								
Space adjacency Visibility		.00	.02	.00	.08	.09	.11	.22
		(.18)	(.18)	(.18)	(.19)	(.18)	(.19)	(.18)
Easy updates		-.89*	-.87	-.89*	-.83	-.76	-.75	-.25
		(.45)	(.46)	(.46)	(.46)	(.45)	(.46)	(.44)
Connectivity log Distance control desk sterile corridor			.06	.02	.07	.16	.14	.11
			(.17)	(.18)	(.18)	(.18)	(.19)	(.17)
Centrality of control desk			-.06	-.03	.01	.07	.08	-.10
			(.18)	(.19)	(.19)	(.18)	(.19)	(.18)
Access area								
Traffic free control desk				-.11	-.09	-.07	-.07	-.11
				(.06)	(.06)	(.06)	(.06)	(.06)
Gathering control desk				.06	.07	.06	.06	.04
				(.06)	(.06)	(.06)	(.06)	(.05)
Barrier-free control desk				-.15	-.11	-.02	-.02	.10
				(.16)	(.16)	(.16)	(.16)	(.16)
Sitting around control desk				-.01	-.02	-.01	.00	.00
				(.09)	(.09)	(.09)	(.09)	(.09)
Information environment								
Communication practice Media					.16	.14	.14	.14
					(.12)	(.12)	(.12)	(.11)
Face-to-face hotspots					-.17	-.22	-.22	-.17
					(.14)	(.14)	(.14)	(.13)
Face-to-face elsewhere					.15	.13	.14	.12
					(.11)	(.10)	(.11)	(.10)
Control desk Information posted						.62*	.61*	.36
						(.28)	(.29)	(.27)
Counters control desk						3.54**	-.09	-.11
						(1.05)	(.09)	(.08)
Coordination processes								
Congregating control desk							-.07	.01
							(.14)	(.13)
Update activity schedule							.00	.03
							(.09)	(.08)
Speed of schedule changes								-.46**
								(.14)
R^2 (R^2 adjusted)	.01	.06	.07	.14	.20	.27	.28	.40
	(-.02)	(.01)	(-.01)	(.01)	(.03)	(.09)	(.06)	(.21)
F full model	.39	1.18	.83	1.07	1.2	1.5	1.3	2.08
Degrees of Freedom	2, 73	4, 71	6, 69	10, 65	13, 62	15, 60	17, 58	18, 57
R^2 Change	.01	.05	.01	.07	.06	.07	0	.12
F Change	.39	1.95	.2	1.4	1.54	2.94*	.12	11.45**
DF Change	2, 73	2, 71	2, 69	4, 65	3, 62	2, 60	2, 58	1, 57

[1] **See Table 5-4 (Chapter 5) for complete variable definitions.**

Table 5-5. Unstandardized coefficients for schedule board and control desk data modeled together. Predicting congregating activity around the schedule board and control desk. Significance levels expressed as * p< .05, and ** p<.01; $^{+}$ p<.15. [1]

	1	2	3	4	5	6	7
Intercept	3.07** (.39)	2.7** (.52)	2.81** (.56)	2.72** (.65)	2.53** (.72)	2.26** (.74)	2.13** (.67)
Control							
Hospital beds	.16 (.15)	.12 (.14)	.13 (.14)	.10 (.14)	-.04 (.15)	-.06 (.15)	-.06 (.14)
Surgeries per room	.04 (.05)	.02 (.05)	.01 (.05)	.02 (.05)	.06 (.05)	.06 (.05)	.07 (.05)
Architecture environment							
Space adjacency							
Visibility		.44** (.14)	.42** (.14)	.34* (.15)	.37* (.15)	.39* (.15)	.32* (.13)
Easy updates		.20 (.35)	.21 (.35)	.20 (.35)	.15 (.35)	.16 (.35)	.09 (.32)
Connectivity							
log distance to sterile corridor			-.14 (.13)	-.14 (.13)	-.04 (.14)	-.06 (.14)	-.10 (.13)
Centrality schedule and control desk			.04 (.09)	.02 (.09)	.03 (.09)	.02 (.09)	.01 (.08)
Access areas							
Traffic free both				-.02 (.06)	-.01 (.06)	.00 (.06)	-.01 (.06)
Gathering both				.03 (.06)	.02 (.06)	.03 (.06)	.01 (.05)
Barriers sterile corridor				-.11 (.08)	-.14 (.07)	-.13 (.07)	-.12 (.07)
Multiple use scale				.10 (.09)	.07 (.08)	.08 (.08)	.07 (.08)
Information environment							
Communication practices							
Media					.24* (.09)	.25** (.09)	.19* (.08)
Face-to-face hotspots					-.07 (.11)	-.08 (.11)	-.06 (.10)
Face-to-face elsewhere					-.01 (.08)	-.02 (.08)	-.06 (.07)
Information aura							
Posters sum						.02 (.09)	.02 (.08)
Counters control desk							.10 (.06)
Coordination processes							
Updates schedule							.22** (.06)
R^2 (R^2 adjusted)	.02 (.00)	.14 (.10)	.17 (.10)	.21 (.10)	.29 (.15)	.32 (.16)	.45 (.31)
F full model	.90	3.11*	2.45*	1.86^{+}	2.04*	1.96*	3.15*
Degrees of Freedom	2, 76	4, 74	6, 72	10, 68	13, 65	15, 63	16, 62
R^2 Change	.02	.12	.03	.04	.08	.03	.13
F Change	.90	5.22**	1.11	.97	2.31^{+}	1.28	14.63**
DF Change	2, 76	2, 74	2, 72	4, 68	3, 65	2, 63	1, 62

[1] **See Table 5-4 (Chapter 5) for complete variable definitions.**

Table 5-6. Hierarchical regressions predicting updating activity around the schedule board and control desk. Unstandardized coefficients for schedule board and control desk data modeled together. Significance levels expressed as * p< .05, and ** p<.01; + p<.15. [1]

	1	2	3	4	5	6	7
(Constant)	2.42** (.68)	1.94* (.94)	1.78 (1.03)	1.31 (1.23)	.58 (1.38)	.60 (1.45)	-1.34 (1.41)
Control							
Hospital beds	.18 (.25)	.17 (.25)	.16 (.26)	.15 (.27)	.02 (.29)	.02 (.30)	.07 (.27)
Surgeries per room	-.08 (.08)	-.10 (.08)	-.10 (.09)	-.10 (.09)	-.06 (.1)	-.06 (.10)	-.11 (.09)
Architecture environment							
Space adjacency							
Visibility		.28 (.25)	.29 (.26)	.27 (.27)	.34 (.28)	.34 (.29)	.00 (.28)
Easy updates		.37 (.64)	.37 (.65)	.31 (.67)	.28 (.68)	.29 (.70)	.15 (.63)
Connectivity							
log distance to sterile corridor			.10 (.24)	.10 (.25)	.19 (.27)	.19 (.27)	.23 (.25)
Centrality schedule and control desk			.03 (.16)	.03 (.17)	.05 (.17)	.05 (.17)	.04 (.15)
Access areas							
Traffic free both				.06 (.12)	.06 (.12)	.06 (.12)	.06 (.11)
Gathering both				.05 (.11)	.06 (.11)	.06 (.11)	.04 (.10)
Barriers sterile corridor				-.02 (.14)	-.06 (.14)	-.06 (.15)	.05 (.14)
Multiple use scale				.10 (.16)	.05 (.16)	.05 (.17)	-.01 (.15)
Information environment							
Communication practices							
Media					.25 (.17)	.25 (.18)	.03 (.17)
Face-to-face hotspots					-.10 (.21)	-.10 (.21)	-.04 (.19)
Face-to-face elsewhere					.16 (.15)	.16 (.16)	.17 (.14)
Information aura							
Posters sum						-.01 (.18)	-.02 (.16)
Counters control desk						-1.34 (1.41)	-.09 (.12)
Coordination processes							
Congregating both							.86** (.22)
R^2 (R^2 adjusted)	.02 (.00)	.04 (-.01)	.04 (-.03)	.05 (-.08)	.11 (-.07)	.11 (-.11)	.28 (.09)
F full model	.91	.82	.56	.39	.60	.50	1.49+
Degrees of Freedom	2, 76	4, 74	6, 72	10, 68	13, 65	15, 63	16, 62
R^2 Change	.02	.02	.00	.01	.05	.00	.17
F Change	.91	.73	.10	.17	1.28	.00	14.63**
DF Change	2, 76	2, 74	2, 72	4, 68	3, 65	2, 63	1, 62

[1] **See Table 5-4 (Chapter 5) for complete variable definitions.**

Table 5-7. Hierarchical regressions predicting coordination speed around the schedule board and control desk. Unstandardized coefficients for schedule board and control desk data modeled together. Significance levels expressed as * p< .05, and ** p<.01; + p<.15. [1]

	1	2	3	4	5	6	7
Intercept	4.03** (.48)	2.76** (.64)	2.96** (.69)	3.18** (.8)	2.8** (.91)	2.97** (.95)	2.33* (1.00)
Control							
Hospital beds	.01 (.18)	.02 (.17)	.02 (.17)	.00 (.17)	.01 (.19)	.01 (.19)	.02 (.19)
Surgeries per room	-.01 (.06)	-.04 (.06)	-.03 (.06)	-.03 (.06)	-.02 (.06)	-.02 (.07)	-.03 (.07)
Architecture environment							
Space adjacency							
Visibility		.33* (.17)	.34* (.17)	.28 (.18)	.26 (.19)	.25 (.19)	.12 (.20)
Easy updates		1.13* (.43)	1.13* (.43)	1.08* (.43)	1.03* (.45)	1.04* (.46)	.97* (.45)
Connectivity							
log distance to sterile corridor			.00 (.16)	.07 (.16)	.04 (.18)	.05 (.18)	.05 (.18)
Centrality schedule and control desk			-.17 (.11)	-.20 (.11)	-.19 (.11)	-.19 (.11)	-.19 (.11)
Access areas							
Traffic free both				.04 (.08)	.04 (.08)	.03 (.08)	.03 (.08)
Gathering both				.00 (.07)	.00 (.07)	.00 (.07)	-.01 (.07)
Barriers sterile corridor				-.16 (.09)	-.16 (.09)	-.16 (.10)	-.12 (.10)
Multiple use scale				-.02 (.10)	-.03 (.11)	-.03 (.11)	-.06 (.11)
Information environment							
Communication practices							
Media					-.02 (.12)	-.02 (.12)	-.11 (.12)
Face-to-face hotspots					.10 (.14)	.10 (.14)	.13 (.14)
Face-to-face elsewhere					.04 (.10)	.04 (.10)	.04 (.10)
Information aura							
Posters sum						-.04 (.12)	-.04 (.11)
Counters control desk						-.06 (.08)	-.08 (.08)
Coordination processes							
Congregating both							.27 (.18)
Updates schedule							.08 (.09)
R^2 (R^2 adjusted)	.00 (-.03)	.12 (.07)	.15 (.08)	.20 (.08)	.21 (.05)	.22 (.03)	.28 (.08)
F full model	.01	2.52*	2.19*	1.7+	1.34	1.17	1.39
Degrees of Freedom	2, 76	4, 74	6, 72	10, 68	13, 65	15, 63	17, 61
R^2 Change	.00	.12	.03	.05	.01	.01	.06
F Change	.01	5.02**	1.47	.97	.31	.29	2.56+
DF Change	2, 76	2, 74	2, 72	4, 68	3, 65	2, 63	2, 61

[1] **See Table 5-4 (Chapter 5) for complete variable definitions.**

Table 5-8. Hierarchical regressions predicting coordination stress around the schedule board and control desk. Unstandardized coefficients for schedule board and control desk data modeled together. Significance levels expressed as * p< .05, and ** p<.01; + p<.15. [1]

	1	2	3	4	5	6	7	8
Intercept	3.16** (.48)	4.04** (.67)	3.87** (.73)	3.79** (.79)	3.6** (.88)	3.63** (.89)	3.67** (.97)	4.61** (.93)
Control								
Hospital beds	-.12 (.18)	-.15 (.18)	-.16 (.18)	-.17 (.17)	-.22 (.18)	-.16 (.18)	-.16 (.18)	-.15 (.17)
Surgeries per room	-.03 (.06)	-.02 (.06)	-.02 (.06)	.01 (.06)	.01 (.06)	.00 (.06)	.00 (.06)	-.01 (.06)
Architecture environment								
Space adjacency								
Visibility		.01 (.18)	.02 (.18)	-.02 (.18)	.07 (.18)	.03 (.18)	.04 (.19)	.09 (.17)
Easy updates		-.88* (.45)	-.88* (.45)	-.75 (.43)	-.67 (.43)	-.79 (.43)	-.79 (.44)	-.39 (.41)
Connectivity								
log distance to sterile corridor			.08 (.17)	-.05 (.16)	.03 (.17)	.07 (.17)	.07 (.17)	.09 (.16)
Centrality schedule and control desk			.06 (.11)	.08 (.11)	.10 (.10)	.13 (.10)	.13 (.11)	.06 (.10)
Access areas								
Traffic free both				-.19* (.08)	-.18* (.07)	-.16* (.07)	-.16* (.08)	-.15* (.07)
Gathering both				.05 (.07)	.06 (.07)	.06 (.07)	.06 (.07)	.06 (.06)
Barriers sterile corridor				.11 (.09)	.08 (.09)	.06 (.09)	.06 (.09)	.01 (.09)
Multiple use scale				.12 (.10)	.10 (.10)	.07 (.10)	.07 (.10)	.05 (.10)
Information environment								
Communication practice								
Media					.15 (.11)	.12 (.11)	.13 (.12)	.08 (.11)
Face-to-face hotspots					-.21 (.13)	-.23 (.13)	-.23 (.13)	-.18 (.12)
Face-to-face elsewhere					.15 (.10)	.16 (.10)	.16 (.10)	.17* (.09)
Information aura								
Posters sum						.20 (.11)	.20 (.11)	.18 (.10)
Counters control desk						3.67** (.97)	-.09 (.08)	-.13 (.08)
Coordination processes								
Congregating both							-.01 (.17)	.09 (.16)
Updates schedule							-.02 (.09)	.01 (.08)
Coordination speed								-.40** (.11)
R^2 (R^2 adjusted)	.01 (-.02)	.06 (.01)	.06 (-.01)	.23 (.11)	.29 (.15)	.33 (.18)	.34 (.15)	.45(.28)
F full model	.35	1.15	.81	1.99*	2.03*	2.11*	1.81*	2.73**
Degrees of Freedom	2, 76	4, 74	6, 72	10, 68	13, 65	15, 63	17, 61	18, 60
R^2 Change	.01	.05	.00	.16	.06	.05	.00	.11
F Change	.35	1.94+	.18	3.60**	1.9+	2.16+	.04	12.49**
DF Change	2, 76	2, 74	2, 72	4, 68	3, 65	2, 63	2, 61	1, 60

[1] See Table 5-4 (Chapter 5) for complete variable definitions.