Architecture and Information Technology as Factors in Surgical Suite Information Sharing and Coordination

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ABSTRACT

Scheduling surgeries in hospitals is one of the most challenging activities for surgical staff. Schedule changes occur as often as every few moments, affecting necessary coordination of tasks, resources, and people within and across staff groups, and the stress people feel. In prior fieldwork at four sites, we observed that the physical layout of hallways and rooms, and barriers and spaces around schedule displays and key coordinators, affected information sharing and coordination of the surgery schedule. To generalize beyond the sites studied, we conducted a survey of 135 surgical suite directors across the USA. Our findings suggest how the architecture of the physical space and information availability and practices influence information sharing and coordination outcomes. Visual access between the shared surgery schedule display and the nursing control desk influenced whether staff groups congregated around schedule boards. Traffic-free areas around the surgery schedule display and up-to-date surgery schedule display information reduced coordination stress. We discuss implications for information practices and new information technology in hospital settings.

Categories and Subject Descriptors

K.4.3 Computers and Society: Organizational Impacts: Computer-supported collaborative work.

General Terms

Human Factors.

Keywords

Coordination; physical environment; shared displays; electronic scheduling; whiteboards

1. INTRODUCTION

High medical costs and the need to improve efficiency, quality, safety, and privacy are leading concerns in hospital-based health

care. Here, we argue that information systems integrated with supportive architectural designs can help address such concerns. Traditionally, architecture and information technology have had little interaction [2]. With the wide dissemination of information technology in hospitals, however, it becomes more relevant to architectural design. For example, hospital technology includes large shared displays, mobile devices, and kiosks (Figure 1). Surgical information systems are traditionally designed to address scheduling constraints, personnel allocation, and supply management, and are focused on operational scheduling (e.g., [8]). Adjustments to surgical schedules often are considered to be independent of hospital design, even though clinical staff, who are constantly on the move throughout large building complexes, must be informed instantly of such changes and often need to talk with each other about these changes [5].
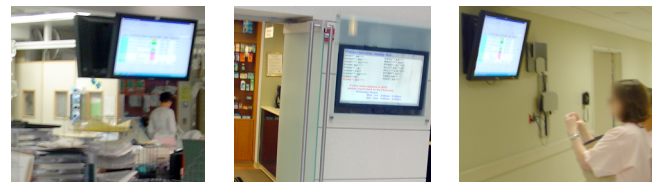

Figure 1. Large displays in a trauma unit (left), prescription display in a hospital pharmacy (center), and electronic schedule board in a surgical suite (right).

1.1 Coordination in Surgical Suites

Scheduling surgeries is difficult due to their uncertain length and the need to accommodate emergencies, complications, staff shortages, workload rules, resource unavailability, patient responses, and other factors. A surgery cancellation risks wasting operating room (OR) space and staff time unless a new surgery replaces the cancelled one. To keep the flow of surgeries constant, changes to the schedule, and to people's locations in physical space, can happen hundred of times daily.

The organizational and social processes surrounding scheduling also cause information systems and architecture to intersect. Many groups—surgeons, anesthesiologists, nurses, and other medical workers—constantly coordinate their tasks on the day of surgery, after schedules for the day have been produced [11]. Ongoing interaction is needed to arrange staff, patients, surgical rooms, and equipment for each surgery [32]. Artifacts, many created by the users themselves, are widely used (e.g., [7]; see Figure 2). In addition to articulation of activities to resolve constraints of

various types [18], staff members are confronted with managing organizational and social conflicts inherent in complex organizations whose workers are distributed in space but whose tasks are tightly coupled ([30], [31]).

Figure 2. A nurse looks at paper based schedule board as two nurses near the control desk discuss.

Uncertainty, variation of work processes, and social conflicts are also reflected in how hospital staff coordinate their work. Informal oral communication dominates coordination ([19], [20]). Staff from different specialty groups negotiate how they will adapt to a schedule change ([23], [24], [26], [28], [31]), for instance by postponing a non-urgent surgery versus requiring nurses to stay overtime. Such negotiations require synchronizing tasks across groups, time, and place, and estimating physical resources and staff workload [4].

To support these work processes, hospital staff rely on a variety of artifacts, including paper schedules, electronic records, schedule boards, and mobile devices (e.g., [29], [33], [21]).

1.2 Coordination in Physical Space

Hospital coordination takes place in distributed physical space. Staff, patients, and equipment move through different hospital areas that are usually highly specialized ([5], [30]). For instance, patients are prepared for surgery in one location, have surgery in a second location, are taken for post-operative care to a third location, and then go to a patient room in still another location. These architectural dimensions of hospitals can significantly impact information access and inter-personal interactions ([15], [27]).

In research organizations, when offices are nearer to each other, co-workers like each other and communicate more [1] and are more likely to co-author papers [17]. Visual and auditory access between workspaces increases communication opportunities whereas barriers such as walls and stairways reduce opportunities for eye contact and conversation [13]. Similarly, the easier it is for people across groups to share scheduling information, the more effectively they will coordinate the schedule. Unfortunately, in many older hospitals in the U.S. and elsewhere, staff who have to coordinate their work are separated by a maze of corridors, stations, and walls.

Researchers have identified two physical locations where staff members are likely to coordinate the surgery schedule. One of these places is the nursing control desk [20]. Today's control desk nurses, especially the charge nurse, play key scheduling roles. They manage the moment-to-moment schedule for the surgical suite, emergency and new "add-on" cases, day-of-surgery support services, work assignments related to transport of patients and specimens, and equipment and supplies for delivery to the surgical suite. People standing at the control desk can discuss the schedule in real time, as the control desk nurses make changes on paper or into a computerized scheduling system.

Another key location for coordinating the schedule is in front of a manual schedule board that displays the schedule and can be updated. A manual schedule board puts information pertaining to different staff groups "in the world," which reduces memory load [22] and mistakes [21]. It serves as a shared tracking system ([3], [16], [32]). The schedule board also provides an interactive physical interface to the schedule. Staff can stand around the board and see changes to the schedule as they are made. Typically, the charge nurse or charge anesthesiologist is responsible for making changes, but others can participate in decision making.

Recently, we conducted a field study in four hospital surgical suites to study the relationship of these hospitals' physical and information environments with the coordination practices and experiences of their staff [25]. We found that rich information was available at the nursing control desk and schedule board, but that the physical dimensions of these places were especially important for facilitating the use of this information. When the architecture of the space made it easy for people to interact with the information and to congregate around information sources to discuss the schedule, coordination seemed to happen faster and staff members were less stressed about schedule changes. For instance, when the control desk and whiteboard were in easy reach of one another, and staff from different services could stand around the whiteboard to negotiate changes to the schedule, coordination seemed to be fairly smooth. When the architecture made information sharing difficult—for instance, when the whiteboard was in an awkward location for people to discuss its information and update the information—coordination appeared to be more difficult, slower, and frustrating.

To examine whether our findings were generalizable beyond the four sites in our qualitative study, we conducted a survey of surgical suite directors across the United States. We examined the relationships among workplace, architecture, information, information sharing practices (congregating and updating the schedule), and coordination outcomes (coordination speed and stress).

2. HYPOTHESES

We studied how the hospitals' workplaces, physical architecture, and information environments were related to the way staff congregated around shared information and updated the surgery schedule, and how those behaviors were related to staff reports of coordination speed and stress (see Figure 3).
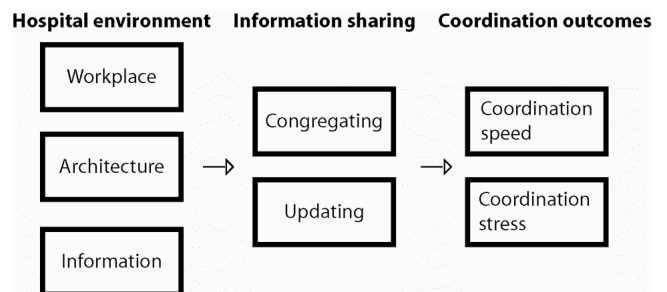
Figure 3. Model of the relationship between architecture and coordination.

2.1 Hospital Environment Variables

Workplace. We asked respondents to describe their hospital (university hospital, affiliated hospital, and unaffiliated hospital), their available surgical specialties (e.g., organ transplantation, neurosurgery, and so forth), and the surgical suite's scheduling load, defined as the number of surgeries per room. We also measured the size of the hospital (number of beds), which reflects the number of employees, patients, services, and overall physical space. We expected larger hospitals to experience more pressure on coordination but perhaps to have better resources for resolving coordination problems.

Architecture. To our knowledge, this is the first survey to look explicitly at the arrangement of physical space in hospital surgical suites. Architecture has effects at the building level, including the configuration and location of rooms and hallways, and at the local level, such as the configuration and location of furniture and objects in rooms and hallways. Based on the literature and previous research [25], we expected the proximity of schedule boards, control desks, and sterile corridors, and the connectivity of these spaces to be positively associated with information sharing (congregating, updating) and coordination outcomes (coordination speed, coordination stress). Also, heavy traffic around the schedule board and control desk could interfere with people's access to scheduling information and 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.

In our previous field study [25], we found that spacious pause locations allowed people to congregate around the schedule board and control desk, and supported multiple compatible activities associated with more frequent congregating. For example, a bench facing the scheduling boards encouraged people to sit, change their shoes, discuss the schedule, and wait for patients, and was positively associated with congregating among different groups and serendipitous coordination opportunities. Without that space, coordination was more difficult. For instance, one schedule board located in a narrow hallway limited the number of people who could read it together. We predicted that more spacious pause locations and/or seating areas would be positively associated with more information sharing and better coordination outcomes.

Information. The information environment includes the mechanisms and technologies that people use to communicate about the schedule. People use manual or electronic schedule boards and computer systems for surgical suite scheduling and billing. They use desk and wall phones, cell phones, pagers, and walkie-talkies to communicate information. An important factor is the amount of pertinent information displayed on schedule boards. In our previous study, the type and amount of information displayed was associated with who updated and paused around the schedule board [25]. Schedule boards placed in a staff-only location included more information because they did not have to worry about revealing patient information to visitors or the public. Furniture oriented to increase exposure to the schedule board increased its accessibility. Larger control boards displayed more scheduling information. We predicted that more detailed scheduling information would be positively associated with better communication and coordination.

2.2 Information Sharing

The two information sharing factors we studied were congregating to discuss information on a schedule board, and updates to the schedule board.

Congregating. Congregating around the schedule board and control desk encourages surgical staff to share information about the schedule. They are likely to become aware of each other's activities and can anticipate coordination problems that may arise from changes to the schedule. As a result, the schedule board can be updated more frequently and coordination speed in the surgical suite can be increased. Faster coordination speed may allow surgical staff more time to adapt to schedule changes and thus reduce coordination stress.

Updating. Updates to the schedule boards have implications for coordinating future work because they give staff a chance to coordinate their work activities and their own schedules. Likewise, given the tightly coupled nature of work by surgeons, nurses, anesthesiologists, and others, these groups often need to discuss schedule changes before the schedule is updated. Thus, we expected congregating around the schedule board to aid updating, and, in turn, for updating to aid congregating to coordinate work. These behaviors should be mutually reinforcing and aid coordination speed and lower stress.

2.3 Coordination Outcomes

Finally, we examined the effects of information sharing on two outcome measures: coordination speed and coordination stress.

Coordination speed. Coordination speed reflects how quickly surgical suite staff learn about changes to the schedule. In our field study, staff 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. We expected that a hospital environment shaped to support more complete information sharing would be associated with greater 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 set up for each surgery according to the patient's specific surgical procedure. Anesthesia drugs and surgical kits must be prepared for surgery patients. Anticipating a schedule change allows staff to avoid scrambling to set up a room, find surgical equipment, and draw anesthesia drugs. The surgical suite staff is under pressure to minimize the turnover time between surgeries and provide safe patient care. Time pressure resulting from delayed or poor coordination increases coordination related stress [24], so coordination speed should reduce coordination stress. Figure 4 is a summary of the hypotheses. No arrows stem from the workplace variables because do not expect these variables to affect congregating, updating, coordination speed, or coordination stress.
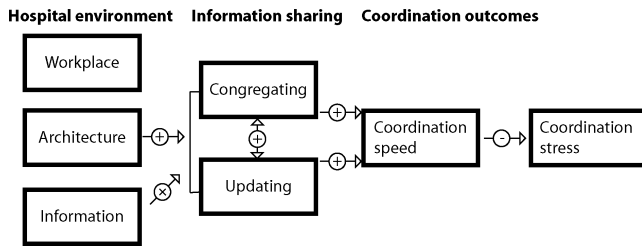
Hospital environment   Information sharing   Coordination outcomes

Figure 4. Summary of hypotheses.

3. METHOD

We tested the hypotheses above with an anonymous mail survey distributed to surgical suite directors. 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.

3.1 Sample and Recruiting

The survey participants were recruited via the Stuart Krasney and associates (SK&A) list (http://www.skainfo.com). This list contained 3828 OR directors from hospitals across the United States. The American Hospital Association lists the number of registered hospitals in the United States as 5,708 as of November, 2008.

Surveys were sent to a random sample of 1200 members from the SK&A list. We mailed the participants a cover letter explaining the purpose of the survey, the survey booklet, and a business reply envelope. One hundred and thirty-five surgical suite directors returned the survey (11.4% response rate). Although a higher response rate would likely have been achievable with repeated contact ([9][10]), the terms of our SK&A agreement allowed only a single contact. We explored differences between respondents and non-respondents to determine possible bias in our sample. We did not detect response bias or coverage error in terms of geographic area of respondents, respondents' hospital type, and hospital size.

Table 1 shows the type of hospital and number of hospital beds reported by our survey respondents. We 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 private hospitals not affiliated with an academic institution.

3.2 Materials

We used a paper booklet in which we asked respondents to describe one schedule board and control desk in their hospital surgical suite. Survey items asked the respondent about the work in his/her suite, how the surgical suite dealt with surgical schedule changes, the surgical schedule board most in use, activities around this board and activities around the control desk.

3.3 Measures

3.3.1 Workplace
Type of hospital. We asked respondents what type of hospital they worked in (i.e., university hospital, affiliated, non-affiliated). Because the preponderance of respondents from non-affiliated (private) hospitals, we did not use this measure in the analyses. Likewise, the majority of respondents were in general critical care

hospitals; hence, we did not use this measure in analyses. (See Table 1.)

Surgical specialties. We asked respondents to indicate the type of surgical services provided on a weekly basis (i.e., cardiac surgery, general surgery, organ transplantation, vascular surgery, etc). They reported a variety of surgical services: general service (97%); orthopedics (91%); urology (75%): otorhinolaryngology (65%); ophthalmology (62%); vascular (53%); plastic/ reconstructive (49%); pediatric (44%); oral maxillofacial (44%); neurology (41%); thoracic (41%); cardiac (27%); interventional radiology (16%); transplantation (9%), and other services (37%). The mean number of services per hotel was 7.66 (SD = 3.33, range = 1 - 14).

Surgeries per surgery room. Respondents were asked "On average, how many [operating rooms, surgeries] are [used, completed] each day?" To measure scheduling load, as in previous field studies, we calculated the scheduling load for each unit as cases per operating room [25].

Hospital size. According to the SK&A list, the number of beds in participants' hospitals ranged from 17 to 695 (M = 199, SD = 164. 61; Table 1). In our analyses of the effects of hospital size, we used a log10 transformation because the distribution had a positive skew.

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

Table 1. Survey respondents' hospital type and beds.

Hospital type	Survey respondents[1] N=113		
	Type	N	Beds
General acute care	71.68%	81	231.48
Long term acute care	7.96%	9	24.67
Critical care access	7.08%	8	23.50
Children	5.31%	6	170.00
University/teaching	1.77%	2	502.50
Veteran admin	1.77%	2	267.50
Military	1.77%	2	108.00
Osteopathic	1.77%	2	297.50
Nursing homes	0.88%	1	50.00
Total	100%	**113**	
Mean			**199.25**

[1] Response rate percentages in this table are for the 113 hospitals that provided hospital type information.

3.3.2 Architecture
Visibility. Visibility between schedule board and control desk was measured by asking participants to indicate, using a five point scale ranging from strongly disagree to strongly agree, whether people at the schedule board and control desk can see each other. Because visibility was positively skewed, and a log transformation was not sufficient to normalize the data, we recoded the data as a binary yes/no item (1-3 = "no", 4-5 = "yes").

Connectivity. We asked respondents to indicate the approximate distance, in feet, between the schedule board and the closest sterile corridor. Given the skewed distribution, a log 10 transformation was applied. We also asked whether the schedule board was located in a sterile corridor or in a main hallway connected to a sterile corridor (no=0, yes =1).

Traffic-free areas. We asked respondents to indicate the extent to which foot traffic interfered with people reading the schedule board, using a 5-point scale ranging from strongly disagree to strongly agree. We inverted the scale such that higher numbers reflected greater freedom from traffic.

Barrier-free area. We asked respondents whether 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. Responses were inverted such that a higher score indicated freedom from barriers.

Access area. We asked respondents how far people could stand from the schedule board and still read most of it (using a 5-point scale ranging from two foot or less to more than eight feet) and how many people could comfortably gather around the schedule board (using a 5-point scale ranging from "2 or less" to "10 or more").

Multiple uses. We asked respondents "How often do people stop by and sit around the schedule board?" and "How often do people drink beverages or eat food around the schedule board?," both using 5-point scales ranging from never to almost continually

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

Communication practices. To gauge communication practices in the surgical suite we asked respondents "On the day of surgery, how often do people coordinate changes to the schedule with face-to-face conversations [at the schedule board, in hallways, workrooms, break rooms]?" and "On the day of surgery, how often do people coordinate schedule changes using [pager (or beeper), phone calls, overhead announcements]. 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 2). From this analysis, we 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 α = .78). The *face-to-face central* scale consisted of three items reflecting face-to-face conversations around the schedule board and around the control desk (Cronbach's α = .68). The *media* scale consisted of three questions about use of phone calls, overhead announcements, and pagers/beepers (Cronbach's α = .55).

Schedule board information displayed. Participants were asked to indicate what information was available on their schedule board via a check list (e.g., time of surgery, OR room number, patient name/initials). We summed the types of information reported. This variable was normally distributed (M=8.59, SD=2.20) so we used it directly as a measure of the amount of information displayed.

Table 2. Communication practices factor loadings.

Measure	Factor Loadings		
	Face-to-face elsewhere	Face-to-face central	Media
FtF hallways	**0.86**	-0.06	0.05
FtF elsewhere	**0.82**	0.22	-0.10
FtF lounges, cafeteria, workrooms	**0.78**	0.04	0.30
FtF schedule board	0.17	**0.81**	0.08
FtF control desk	0.13	**0.76**	0.19
Checks board	-0.12	**0.73**	0.18
Pager (or beeper)	0.06	0.31	**0.72**
Announcements	0.03	-0.02	**0.71**
Phone calls	0.10	0.23	**0.64**

Posters around the schedule board. We measured the availability of surfaces to host information by asking how many papers, posters, post-it notes, or contact lists were posted around the schedule board. We split the response distribution in half to create a binary measure (0 = few items; 1 = many items).

Schedule board surface. We asked participants to estimate the size and position of the schedule board. We calculated the surface of the display boards in square inches. Given the positively skewed distribution, we applied a log 10 transformation. We also asked the participants to estimate the distance from the bottom of the board to the floor, in inches.

Display type was measured by asking participants to indicate which of several pictures of surgical suite displays was most like the one they used: a handwritten whiteboard, a whiteboard with magnetic strips, a large electronic display, or "other". We also asked how many schedule boards were used in their surgical suite (M=2.20, SD=3.17). Given positive skew in the distribution, we recoded the number of displays as 1, 2, or "3 or more" displays.

3.3.4 Information sharing
Congregating. We asked respondents to estimate how often charge nurses, control desk staff, nurses, charge anesthesiologists, the anesthesia team, surgeons, housekeeping staff, congregated around the scheduling board, using a five point scale ranging from "not at all" to "frequently during the day." The seven items formed a reliable scale (Cronbach's α=.78). We asked the same set of questions about congregating around the control desk (Cronbach's α = .79).

Schedule board updating. We asked respondents to estimate, using five point scales ranging from "not at all" to "almost continually during the day," who updates the schedule board and how often they update it. The four roles centrally engaged in surgery schedule coordination (charge nurse, charge anesthesiologist, surgical suite nurses, and anesthesia team members) formed a reliable scale (Cronbach's α=.65) and were averaged to create the updating activity measure.

3.4 Coordination Outcomes
We assessed coordination with two related measures: coordination speed and coordination stress.

Coordination speed. We measured speed as the amount of time it took different groups to learn about changes to the surgical suite schedule. We asked respondents "On the day of surgery, how quickly do the following people [charge nurse, charge anesthesiologist, surgeons, surgical suite nursing staff, anesthesia staff] learn about changes to the schedule?" We used five-point scales ranging from "longer than an hour" to "almost immediately." The five questions formed a reliable scale (α = .84), and we averaged them to create our coordination speed measure.

Coordination stress. We used five Likert-type items about the effort and stress required to learn about schedule changes. Respondents assessed their agreement with a set of statements, including "People adapt easily to schedule changes," and "People have to run around to learn about schedule changes." The five items created a reliable scale (Cronbach's α = .73), and we averaged the values for our coordination stress measure.

4. RESULTS

4.1 Statistical Approach

We used hierarchical multiple regressions to test how architecture and information variables predicted each of the four main coordination variables—congregating around the schedule board, schedule board updating, coordination speed, and coordination stress. We used hierarchical regression because it allows us to see how much each block of variables (where blocks are roughly equivalent to the concepts of interest) contributes to the coordination factor of interest. The underlying theoretical framework, derived from previous field studies, specifies relationships between variables and thus the block order (see Figure 4).

For each analysis, the first block of variables included our two control variables. Block 2 contained variables pertaining to the architecture, including visibility, connectivity, and access areas. Block 3 contained variables pertaining to the information environment, including communication practices and schedule board characteristics (see Table 3). We added additional blocks to specific regressions to test various components of the model (e.g., congregating was a predictor for coordination speed). For each block, we present the overall R^2 for the regression including that block and all preceding blocks (if any). We also present the F value (F_{Change}) testing the significance of any increase in R^2 resulting from adding that block to the previous model.

4.2 Control Variables

The workplace (e.g., type of hospital, type of surgical suite, surgical specialties) and the scheduling load (e.g., cases per room, number of add-on cases) can affect coordination, independent of the architecture and information environment variables of interest [25]. Because many of these measures were highly correlated, we selected two for use in our analyses: number of beds (a proxy for hospital size) and number of surgeries per operating room (a proxy for scheduling load).

4.3 Main Analyses

Of the 135 respondents, 104 reported both a control desk and at least one schedule board. For the analyses in this section, we used the 70 of these 104 respondents who provided complete data. We also ran the models with imputed means for missing data. The

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Table 3. Regression variable blocks.

Block 1: Workplace control variables
    Number of beds
    Surgeries per operating room.

Block 2: Architecture variables
    Visibility between schedule board and control desk
    Ease of updating the schedule board
    Distance to the sterile corridor
    Centrality of board with respect to the main corridor
    Traffic free area around schedule board
    Number of people who can gather around the board
    Barrier-free area around schedule board
    Sitting around schedule board

Block 3: Information variables
    Face-to-face conversation outside schedule area
    Face-to-face conversation in central schedule areas
    Mediated communication (phones, etc.)
    Types of info posted on the schedule board
    Posters around the schedule board
    Schedule board size
    Electronic vs. manual schedule board

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results we report are very similar to the pattern of results with imputed means for the missing data.

Congregating. Our first set of analyses focused on staff congregating around the schedule board. We performed a hierarchical regression using blocks 1-3 from Table 4 and schedule board updating entered as block 4. The control variables alone did not account for significant variance in congregating (R^2 = .04). Adding architecture measures led to a significant improvement in prediction (R^2 = .37; F_{Change} [8, 56] = 3.68, p. = .002). Further adding information variables 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).

We examined the significance of each variable in the final model. Although the block of workplace variables was not significant in itself, there was a significant negative effect of number of beds in the final model (t = -2.72, p < .01). With respect to architectural features, visibility between the schedule board and control desk was associated with significantly more congregating (t = 2.48, p = .01). There was also a trend for more congregating to occur around schedule boards when there is space to accommodate more people standing around them (t = 1.66, p = .10). With respect to the information environment, two communication practices influenced congregating. When staff tended to coordinate schedule changes face-to-face 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). 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). Also, when schedule boards were updated more frequently, congregating around these boards was greater (t = 2.04, p < .05).

Schedule board updating. Next, we examined the frequency of updates to the schedule board using blocks 1-3 from Table 4 and our congregating measure in block 4. Control variables alone were poor predictors (R^2 = .01, ns). Adding architecture variables failed

to improve the model (R^2 = .09; ns), as did adding information environment variables (R^2 = .22). However, adding congregating to the model did significantly improve prediction (R^2 = .28; F_{Change} [1, 48] = 4.17, p. < .05). The only significant effect in the full model 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 of schedule changes in workrooms, hallways, cafeterias, and break rooms (t=1.82, p=.08).

Coordination speed. The third set of analyses examined the average amount of time it took people in different roles to find out about schedule changes. The first three regression models were the same as those above. In the fourth model, we added the two information-sharing variables: congregating and updating.

The control variables alone did not account for significant variance in coordination speed (R^2 = .01, ns). Adding architecture variables led to a significant improvement in prediction (R^2 = .32; F_{Change} [8, 56] = 3.15, p. = .005), but adding information environment variables did not lead to further improvement (R^2 = .40; F_{Change} [7, 49] = 1.04, ns). Adding the two information sharing variables, congregating and updating activity, likewise did not improve prediction (R^2 = .41; F_{Change} [2, 47] = .09, ns). 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).

Coordination stress. The fourth set of regressions examined coordination stress. We expected that greater coordination speed would reduce coordination stress. The first four blocks were the same as in the previous analysis. In the fifth block, we added coordination speed as a predictor variable.

The control variables alone again accounted for virtually no variance in coordination stress. Adding architecture variables led to a significant improvement in prediction (R^2 = .31; F_{Change} [8, 56] = 2.79, p. = .01). Adding information environment variables 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, did not improve prediction (R^2 = .51; F_{Change} [2, 48] = .42, ns), but adding coordination speed to the model significantly improved prediction (R^2 = .60; F_{Change} [1, 47] = 11.04, p = .002).

In the final model, 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). 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 controlling for information content, when the overall dimensions of the board were greater, self-reported stress was higher (t = 1.9, p = .05). 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).

5. DISCUSSION

As in our prior qualitative field study, our survey results point to the importance of physical architecture, information technology, and communication practices in information sharing and coordination of the surgical schedule in hospitals. Figure 5 shows the main significant relationships from the survey.

The results summarized in Figure 5 are correlational and cannot be interpreted as demonstrating causality. Although it is reasonable to assume that none of the information sharing or coordination behaviors we observed caused differences in the architecture of the hospital, it cannot be likewise assumed that architecture (or information) caused the behaviors we saw. Unmeasured factors, such as the financial resources or newness of the hospital, might have caused the relationships we observed to occur. For example, wealthier hospitals might put more resources into training staff in coordination and more convenient spaces for coordination across groups. Thus our interpretations of our results must stand as speculative and should be followed up with more focused evaluations, perhaps after planned, controlled field trials.
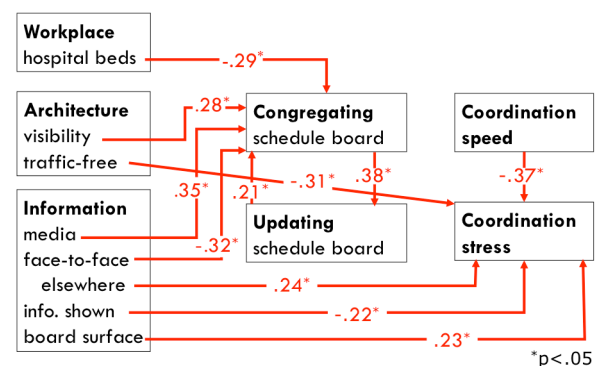
Figure 5. Summary of findings. Lines represent significant linkages from the regression analysis. The numbers are standardized regression coefficients.

Regarding the workplace, we found that hospital size (but not surgery room scheduling load) was negatively associated with congregating around the schedule board, which in turn was associated with updating information on the board. This finding suggests that hospitals with large staffs, many patients, and/or big spaces are less likely to use interaction across groups around schedule boards to negotiate and discuss scheduling. Our findings are reminiscent of findings from research on other large institutions, showing they have social interaction practices that are very different than those in small institutions (e.g., [6]). Large institutions are likely to have greater bureaucracy, including more centralization and more division of labor. Perhaps, in large hospital surgical suites, schedule boards are more specialized, or scheduling is more top-down and allows for less informal negotiation across groups. This result merits further investigation because it has implications for differential planning of coordination and spaces for large versus small hospitals.

We had hypothesized that architecture and information factors would affect coordination behaviors and outcomes, and we see some indirect and direct effects in this study. The visibility between the schedule board and control desk was the primary architectural factor that affected congregating around the board, implying that these two central areas of information exchange need to be connected visually (and, by implication, be situated close to one another). Another architectural variable, traffic-free areas around the board, had direct effects on coordination stress.

We suspect that this effect may be connected with how people managed time pressures. Being able to move freely in space to check the board seems to have lowered staff coordination stress. Alternatively, traffic-free areas might be associated with fewer people traversing hallways, implying better-designed arrangements of staff and patients in physical space.

Several aspects of the information environment were important for coordination. Staff who relied heavily on mediated communication, such as cell phones and pagers, congregated more frequently around the schedule board, a result we did not expect. In retrospect, we speculate that calls from people about the schedule drove them to areas where they could negotiate the schedule and coordinate their work with others. For example, a surgeon notified of a room change might stop by the control desk to request further changes. We bring this point up later, because it bears on the advent of distributing scheduling information in smart phones and other handheld technologies.

We also confirmed a hypothesized relationship: Staff who relied heavily on face-to-face communication in locations such as the cafeteria also congregated less around the board. Furthermore, this behavior was associated with higher stress. These results, in conjunction with the effects for mediated communication practices described above, suggest that use of the information on the schedule boards and around the control desk, as well as congregating around those two areas (perhaps motivated by pager and phone notifications), was a better way to handle the coordination of scheduling changes than was catching people in hallways, the cafeteria, and other non-central areas.

When the scheduling board contained more detailed information, such as patient names, the type of surgery, and the surgeon assigned to the case, staff experienced less stress. (Larger board surface alone, absent information, was associated with more stress.) These results indicate the importance of placing a scheduling board within staff-only areas in order to protect patient privacy. This echoes a finding from one surgical suite we observed in our previous study [25], in which the schedule board was placed where visitors could read it and as a result, there was very little useful scheduling information displayed on that board. However, a policy of placing shared schedule boards in staff-only areas might be incompatible with family-friendly practices in some hospitals that allow visitors broad and free access to patients and nursing control desks. Perhaps coded information known only to staff should be shown on the board and would solve these conflicting mandates.

We had predicted that the frequency with which the schedule board was updated would also be influenced by features of both the architecture and the information technology. Contrary to our expectations, neither of these factors was significantly associated with updating activity. It seems, on the contrary, that updating was performed independent of these factors (and likely related to routines required of staff). On the other hand, updating was highly related to congregating—congregating predicted updating and vice versa, a reciprocal relationship. These results indicate that information sharing surrounding scheduling activities involves not just the transfer of information but also a social process of discussing and negotiating the schedule.

A surprising result of the survey was that the speed of coordination—how quickly people learned of schedule changes—was not predicted by either how much staff congregated around the schedule board or how often they updated the schedule. In retrospect, we suspect that coordination speed, as we measured it in this self-report survey, had more to do with curvilinear perceptual processes rather than reality, related to the amount of effort involved in aligning people's work with scheduling changes. Staff members who had to negotiate the schedule continually and deal with many updates may have perceived coordination speed to be slow (because so many scheduling events took up time). At the same time, those who were apprised of few or late updates also would have found coordination speed to be slow. These two trends would have cancelled out any gains in efficiency from congregating around the board. Supporting this idea is the finding that rating coordination as slow was associated with higher coordination stress.

5.1 Implications

This study has implications for how architecture, along with information technology and practices surrounding that technology, affect what hospital staff know, how they coordinate across groups, patient welfare, and hospital efficiency.

Our study implies that information and physical space are hospital resources whose integration is important to the success of coordination. Thus, information technology to track patients and re-schedule surgeries needs to be located where people can easily access up-to-date information as they move around the hospital. Also, people want to have input into the scheduling process. We argue that the better informed different groups are, and the more they can negotiate and coordinate their roles, the less likely there will be frustrated, unhappy staff, prepped patients waiting for hours for a surgery, and mistakes in scheduling.

Someday, automated scheduling based on preferences will be perfected, but today it is remains a daunting challenge. Throughout the day, many considerations of each group—nurses, anesthesiologists, surgeons, and others—need to be factored into the multitude of scheduling decisions that take place. We believe that the design of physical spaces for holding and displaying shared scheduling information across groups remains essential. Prior studies have shown the importance of inter-group communication and good working relationships among nurses, anesthesiologists, surgeons, and other professional groups in hospital surgical suites [24]. Thus spaces for coordination should not be considered as independent areas (e.g., control desk for nurses vs. whiteboard for anesthesiologists) but as opportunities for information sharing and cross-group communication, whereby staff can negotiate changes to the schedule in real time and discuss the reasons for, and consequences of, updates as they are happening.

Unfortunately, there are currently no widely-accepted planning guidelines for architects and designers of hospitals that would help them design appropriate physical layouts of information areas and connections among them. In our field study [25], we saw whiteboards and other shared information areas and content added over time, sometimes making the physical arrangement worse for supporting coordination. For example, a scheduling whiteboard requested by staff in one surgical suite was placed in a narrow but traffic-filled hallway where people could not stop to discuss the board without blocking others' passage. In another surgical suite, an electronic board was placed high above people's heads, where they could neither discuss the schedule comfortably nor interact with it. Our findings suggest that guidelines for supporting coordination, integrating architecture and information

technology are badly needed, and should be developed as new information technology is developed for hospitals.

In the near future (already in some hospitals), scheduling information will be distributed to handheld devices (e.g., [12], [14], [29]). Some of the designs we have seen obviate group discussions around the schedule. Our findings have implications for the dissemination of this new distributed scheduling technology in hospitals. As we have implied above, and as the literature shows convincingly [3], scheduling is not simply an information process. It is also a social process whereby individuals and groups interact in real time to solve problems. These problems are not simply those of the moment, for example, how to find another operating room for a surgeon whose previously scheduled room has been taken for an emergency procedure. They are also problems related to the staffing practices of the hospital (e.g., is someone available to move a heavy patient to a different operating room), to the financial status of the hospital and practitioners (e.g., cancelling a surgery because of changes to the schedule has implications for the room's and surgeon's revenue), and patient and family welfare (e.g., patient has been waiting for hours with family members who have already missed hours of work). If scheduling information is considered only an information process and becomes one way, sent to mobile devices in the same manner as has happened with many electronic scheduling boards, how will staff participate in the scheduling process? Experience with electronic boards suggests that new strategies will be needed to allow for discussion around the schedule. Our data point to one possible solution. That is, we found that those who used cell phones and other mediated communication technology to interact around the schedule also congregated more around scheduling boards. This unexpected result suggests to us an opportunity to design applications for handheld devices that could support synchronous or near synchronous interaction around distributed scheduling. For example, staff receiving schedule updates on handheld devices might be able to input comments to respond to this information and discuss it with scheduling coordinators and other staff.

6. SUMMARY

This survey study examined the architecture surrounding central coordination spaces in surgical suites, and the information and coordination practices of staff in those spaces. We identified some key factors involving both physical space and information technology that were significantly related to information sharing around the schedule and coordination outcomes.

7. ACKNOWLEDGMENTS

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