international journal of medical informatics 76S (2007) S261–S266

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Emergent CSCW systems: The resolution and bandwidth of workplaces

Yan Xiao[*], *F. Jacob Seagull*

Division of Research in Patient Safety, Program in Trauma University of Maryland School of Medicine, Baltimore, MD, USA

ARTICLE INFO

Article history:
Received 5 March 2006
Accepted 11 May 2006

Keywords:
Computer supported cooperative work
Coordination
Artifacts
Clinical information systems
User interfaces

ABSTRACT

In any collaborative work settings, people naturally develop physical tools and associated work processes that support the management of the interdependencies in information, materials, and social needs. Field studies of management of operating rooms pointed out that collaborative work is supported by an infrastructure that is composed of mostly non-computerized, physical components. The supporting infrastructure is jointly maintained and exploited, with constantly evolving patterns of usage, in response to complexity of coordination needs and the uncertain environment. To represent status and plans, users seem to invent structures based both on idiosyncratic preferences and on negotiated symbols. The fluidity and ease of restructuring workplaces to support collaborative work may be explained in part by the high resolution and bandwidth of workplaces: a large number of ways in which workers could structure their work and a high capacity to convey rich information and meanings quickly to collaborators. We argue that to support health care workers, designers of computer supported cooperative work (CSCW) systems should learn how the physical and perceptual properties of workplaces are exploited, and that CSCW systems should be designed to allow maximum freedom of restructuring and reconfiguring as part of workplaces to enhance bandwidth and resolution of representation and communication.
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1. Introduction

Computerized information and communication technology (ICT) has rapidly changed how work is performed and its use has been advocated for a number of reasons (e.g. [1]). How to harness the ever increasing power of the digital world of computing has become a challenge to many, as the introduction of large information systems is not always successful, despite the intuitive appeal of speed, accuracy, and convenience [2]. Healthcare is characterized by the collective nature of work because of demands for specialization of expertise and facilities. Such collective nature results in two, interrelated sides in harnessing ICT. First, collaborative work often means added efforts in the management of interdependencies of information and materials. ICT can potentially facilitate the information flow thus collaborative work. Second, ICT is likely to change and indeed redefine how work is carried out among workers. A simple example would be ICT-adoption related task redistribution of data input, often demanded by information technology. This example was demonstrated in automated air traffic control systems [3]. These two sides of issues could also be stated as how to leverage ICT for its potential beneficial impact and how to minimize its potential negative impact.

In this article, we follow the long tradition of understanding work in its natural context to address questions related to these two sides of information technology. Over the last 4

* *Corresponding author at*: 685 W. Baltimore Street, MSTF 534, Baltimore, MD 21201, USA. Tel.: +1 410 706 1859; fax: +1 410 706 2550.
E-mail address: YXiao@umaryland.edu (Y. Xiao).
URL: http://hfrp.umaryland.edu/.

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doi:10.1016/j.ijmedinf.2006.05.037

years observational studies have been carried out to understand the collaborative work involved in the management of surgical operating rooms. The physical artifacts used and the ways they were exploited in supporting collaborative work were closely examined to appreciate the interaction between people and their workplaces. In this article, we attempt to provide suggestions on important characteristics of artifacts that workers find useful and that should be considered in the design of computer supported cooperative work (CSCW) systems. In particular, we propose the concepts of resolution and bandwidth of workplaces, as a way to provide insight into design of CSCW systems and potential impacts of CSCW on collaborative work.

2. Analytical framework

The interactive nature of individual human cognition and environment has been highlighted by the notions of affordance (e.g. [4]) and display-based cognition (e.g. [5]). Similarly, the roles of physical objects in collective work are made significant by observations in work settings, such as navigation (e.g. [6]). Observations in an airline operations room, for example, illustrate how paper forms (complex sheets) are exploited to facilitate production of joint work [7]. Suchman and Trigg [7] reported that complex sheets performed an essential role in getting workers on the same page in terms of understanding intended plans. Furthermore, the researchers discovered that complex forms were being continually modified and were in fact a "medium" for notation of changes.

Studies of "flight strips" provide interesting insights into how seemingly low-tech paper artifacts support collaborative work [3,8,9]. Flight strips are paper cards used to manage flights by individual air traffic controllers. Since flight strips are physical artifacts, their manipulation (such as rearranging, removing, or inserting a new one) would provide visual cues to neighboring controllers. An experimental video system to enable remote visual access to flight strips was shown to be valuable [8]. In control centers where computerized systems were used, Mackay [3] found that various paper artifacts are used. She concluded that "attempts to radically change work practices that have successfully evolved over the past 50 years will almost certainly fail to account for all the embedded, intangible safety factors and are likely to result in dangerous, perhaps fatal, situations" (p. 337). An intriguing yet mundane example of artifacts supporting collaborative work is the "spindle wheel" in the short-order restaurant industry ([10] p. 393), where the spindle wheel holds paper order slips in sequence to coordinate the work between waitresses and the cook. The cook could reorganize work such as materials preparation based on all the pending orders, and the waitresses could view overall workload to their advantage such as information on potential wait time of their orders.

Several other examples on emergency response dispatch centers [11,12], a trading room [13], an underground train control room [14] and medical records [15] have suggested that in nearly all collaborative work settings, an "infrastructure" is in place to support the articulation of individual activities in significant ways, such as providing awareness and facilitating communication. The infrastructure would include physical objects such as computer printouts, paper forms, paper checklists, bulletin boards, whiteboards, or even work objects such as syringes and medications. Along with the physical supporting infrastructure are traditions, formal and informal agreements and a common accepted symbology in interpreting meanings as conveyed by different configuration of physical objects in the infrastructure [16].

In a sense a workplace is an emergent "CSCW" system, which users configure and adapt to meet the demands of collaborative work, the nature of which usually change over time. From this point of view, ICT systems deployed are essentially one component inserted into existing infrastructure that supports collaborative work. In healthcare, very rarely is ICT used in isolation, but rather it is always used in conjunction with other components. We will use this framework to examine how two types of artifacts are used in the management of operating rooms.

3. Materials and methods

We based our observational studies in a six-room surgical unit in a dedicated trauma hospital. As in most workplaces, a combination of computerized and manual scheduling systems was used. Management of materials, staff, and operating room access was assisted by a multitude of computerized scheduling and calendar systems installed over time. Printouts were distributed and posted, which were annotated.

Observations and opportunistic short discussions with workers were carried out, with the assistances of photographs and notes. Over 200 photos were taken in more than 60 observation days over the span of 4 years. We encountered many examples of information rich areas in the workplaces, such as the one illustrated by Fig. 1 where the work environment was tailored and configured to provide easy access to information.

Fig. 1 – A portion of the infrastructure supporting collaborative work. Artifacts, such as list of contact numbers and on-call schedules, are placed near the telephone. Although appearing messy, the artifacts are frequently used and updated.

Fig. 2 – The whiteboard used for management of operating rooms in a trauma center. On the left are magnetic strips with information about planned surgeries.

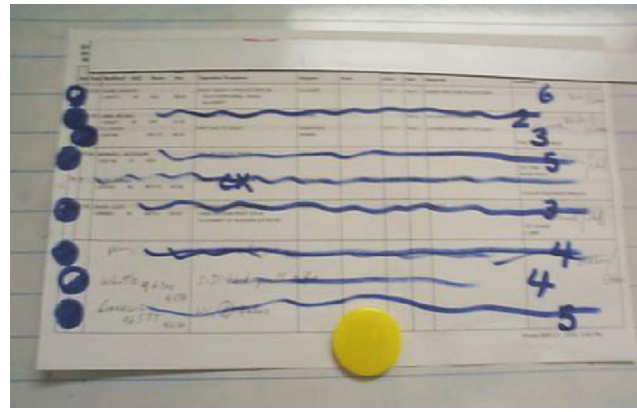

Fig. 3 – Annotated printout of a surgical schedule, as seen at the end of a day. The printout was on a legal-sized paper and was put on a whiteboard in a staff (anesthesia) lounge.

Although a number of other artifacts are in use, we focused on the use of two artifacts: a large whiteboard and printout of surgical schedules. The two artifacts focused were chosen because of their dynamic changes over the course of a day.

The whiteboard (Fig. 2) is located in a convenient gathering point yet the access is restricted to staff. The public nature of the board encourages communal management of activities in the operating rooms, with people voluntarily updating the whiteboard with information to which they have easy or special access, such as staffing schedules or surgical plans. Previously we have reported one aspect of the whiteboard: how the whiteboard, as a public display, is used to support coordination [17] from the point of view of supporting joint cognition. Patient transportation slips, seen as small pieces of paper placed under magnetic strips in Fig. 2, were one type of physical objects used. The slips had key information items about the logistics of transporting patients into the operating rooms. These items include the need for ventilation support and intravenous infusion devices during transport, as well the current location of the patient. The transportation slips provided a condensed, compiled information summary gathered from different sources to facilitate safe and efficient patient transport.

Printouts of surgical schedules (Fig. 3) are carried by several coordinators. Although schedule surgical cases are often changed at the start of a day, the printouts are usually not regenerated. Rather, they are annotated with the changes, along with other information relevant to the owners of the printouts. In Fig. 3, for example, the owner was an anesthesiologist, who made notes on progress of duties to be performed by anesthesia care providers.

4. Results

4.1. *Compatibility of physical information artifacts with workflow*

Physical information artifacts, such as printed schedules and patient transportation slips, were in common use. These physical information artifacts were used together with other physical objects as part of care processes. In general, the physical information artifacts appeared to be compatible with the workflow, especial in comparison with those information items stored on computers. The transport technicians, for example, were observed to take the slips with them on their way to pick up the patient. The absence of the slip would indicate that someone had taken the task assignment of transporting the patient. Thus the artifact served both as an information repository for the transport technician as well as a task status indicator for those looking at the whiteboard. The ease of integration of physical elements into collaborative workspace made physical artifacts adapt well to mobility of workers, constant changing status, and constant hand-offs of tasks, as these objects were passed and rearranged in workplaces.

4.2. *Complexity of work being represented by inventive use of the whiteboard*

Efficient and smooth management of surgical operating rooms requires the appreciation of the nuances of many elements, such as surgery progress in a room for anticipation of ending time, medical urgency of a planned surgery case, special patient conditions, and composition of surgical teams. There is much uncertainty and unpredictability in these elements. This challenge was met with inventive uses of the physical properties afforded by the whiteboard, such as various visual cues, proximity of objects, orientations, colors, fonts, and shapes. For example, when a case neared its completion, attending surgeons frequently tilted the relevant strip to indicate the status of the case (e.g. sloping downward for "ramping down" or finishing soon).

4.3. *Emergent structure of information presentation*

There were no apparent *a priori* structures on the whiteboard. The structures on the whiteboard could be seen as the result of the interaction between the users and displays. Through interaction the users established structures, which were fluid and emergent. Newcomers, such as rotating residents, were sometimes puzzled by the symbols used, such as the significance of a "green" magnet (for isolation precaution). Different coordinators also invented different use of objects and symbols. Similarly, the printouts were almost always annotated in idiosyncratic manners (see the filled and half filled circles, indicating anesthesia care progress, in Fig. 3).

4.4. *Adaptive use of artifacts in response to emergent needs*

We observed numerous examples of structures being invented to reflect the needs of collaborative work, in the form of storing status of work, expressing plans and intentions, tracking, and communicating to others. For example, a coordinator was observed to use the whiteboard to track the attendance status of surgical nurses in a training course. To attend the training course, a nurse had to be out of the operating room for 15 min, during which he or she had to be relieved of the operating room duties. To achieve the goal, the nurses were relieved one at a time to attend the training course by another stand-by nurse. The training course was a one-time requirement. The coordinator used, on the fly, a special symbol on the whiteboard to indicate the training status of the nurses to facilitate the coordination of the extra task.

4.5. *Seemingly unconstrained methods of representation*

The whiteboard and the surgical schedule printouts seemed to constrain little how structures were developed. These physical information artifacts allowed or even encouraged users to discover and settle into structures for effective and efficient communication and representation. We observed few reservations on the part of users in terms of keeping the representation to some standard structures, or of maintaining the structures beyond the lifetime (e.g. a day) of the representation.

4.6. *Ease of incorporating new display elements*

We observed frequent introduction of physical display elements into the whiteboard. The users seemed unconcerned about compatibility of new objects with old ones. One set of magnets was used to indicate the shift schedules at the start of our studies. Over the course of the 4 years, three other sets were seen to represent the same information.

4.7. *Joint management of the whiteboard*

Users collaboratively developed evolving structures in the whiteboard and jointly managed (updating and correcting) the whiteboard. The users did not seem concerned about the possibility that multiple users might update the whiteboard. In fact due to the distributed nature of information access, such possibility was viewed as a plus. As in the example described earlier on tilting case strips, the attending surgeon operating on a patient had best access to the information on the progress of a surgery. When she handed off a case to other junior surgeons to complete, usually the case was about to finish. We also observed that assisting surgeons put their names and pager numbers onto case strips, so that they could be called when a case was about to start. These surgeons were not listed in scheduling systems, but they had the best knowledge on the level of their involvement in the scheduled cases.

5. Discussion

Field observations reported here outline a set of characteristics of the studied workplaces that seem key to supporting collaborative work in dynamic, high stakes settings. The workplaces were tailored, on a continual basis, to support the constantly changing patterns of collaborative work. Physical artifacts are widely used and their perceptual and physical properties are adeptly exploited to simplify articulation efforts and improve workflow. We also suspect that workers may draw satisfaction from creating and adapting symbols in the "emergent" CSCW system.

The flexibility found in the studied setting of the emergent, "accidental" CSCW system, as it were, was remarkable. The flexibility, more than the specific forms or functions uncovered, was the key characteristic of the system. We propose that the flexibility is not just the fact that the artifacts are physical objects [18], but it is a result of high "resolution" and "bandwidth" of the supporting infrastructure, in comparison to how current CSCW systems are designed and used. The complexity of hospital work, both in terms of social organizations and work processes, demands ability of the underlying supporting infrastructure to represent and convey rich information and all the subtleties and nuances in complex organizations with inherent conflicts. The "resolution" and "bandwidth" of the physical artifacts are high when one considers the ability of users to easily impose structures and meanings into the workspace. By *resolution*, we mean the number of ways in which users could restructure workplaces to represent intended plans or status; by *bandwidth*, we mean the capacity in which information and meaning is conveyed to collaborators. In particular, new physical components could be added or changed as situation demands, making the supporting infrastructure extensible. In contrast, current CSCW systems are often poor in these two regards: inflexibility in composing new structures and inflexibility in modifying structures to suit tasks at hand. As a result, often incompatible means are developed to compensate shortcomings in computerized information systems.

How would the power of advanced information technology be harnessed to participate effectively as part of the supporting infrastructure? Based on the analysis presented here, we suggest two general directions, one for modeling and one for strategies of incorporating information technology solutions.

Workplaces, as perceived as a supporting infrastructure for collaborative work, are configured by users not according to pre-planned structures. Rather, the structures for information presentation are emergent. Users constantly change workplaces, assign structures and attach evolving meanings for representing work process to reflect inevitable contingencies. We should model how structures are developed and changed, as opposed to viewing structures as static and having CSCW systems assume those structures. For example, users frequently interact with information systems through paper printouts and then annotate on papers. Yet little research has been reported on how such practices might be modeled. Another example was reported by a study of "bed board" [19], in which subtleties in status of beds in a hospital were represented by slanting of cards, whereas in information systems the status of beds had only one bit of information: occupied or unoccupied. Constraining users to these two choices was confronted by the creation of a physical board, which provided the increased resolution needed by workers. Additionally, ethnographic studies of work in medical collaboration are much needed to understand how collaborative work is carried out, especially in terms of physical artifacts used [18]. We believe that our observations are examples of what one might gain by such studies.

Due to the inevitable shortcomings in anticipating exactly the needs of collaborating workers in any complex work settings, CSCW systems should be designed to support the emergent interaction: help users in restructuring, assigning meanings, and developing new structures. One implication of this insight is our proposal that CSCW systems should be designed as modular components, compatible to physical forms that would fit well with the physical activities of workplaces, thus allowing extensive tailoring and restructuring. Through interaction, the users would be encouraged, as opposed discouraged or limited, in discovering new structures within workplaces that contain computerized components. Recent advances in tangible user interface (e.g. [20,21]) and embedded information objects (e.g. [22]) point to an exciting trend of a modular approach of inserting information technology in non-obtrusive ways into existing infrastructure of support for collaborative work. Tangible interfaces provide tangible information objects with ICT capabilities, perhaps augmented with digital displays of information in hybrid manners. Instead of assuming the functions of a physical whiteboard, new forms of CSCW systems may be designed to allow the users to incorporate functions afforded only through ICT, such as remote displays and access to databases. For example, sensors may be used to detect positions and contents of magnetic strips in the studied whiteboard reported earlier while networked databases (e.g. operating room schedules) may be visually projected onto the whiteboard among the magnetic strips. Recently a prototype of such a tangible interface for the whiteboard was developed [22]. The prototype embedded on the whiteboard networked digital information about operating room status (such as start- and ending times for surgeries) and low quality video images of each operating room. Such an approach does not limit the bandwidth and resolution of the workplace, as the users can exploit what the new information technology has to offer without losing the resolution and bandwidth afforded by physical objects. Perhaps it is a case where healthcare should not only accept more ICT, but also demand more of the compatible types of ICT.

Acknowledgments

This material is based upon work supported in part by the National Science Foundation under Grant nos. 0081868 & 0325087. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The paper benefits contribution from members of the Human Factors and Technology Group at the University of Maryland (especially Jackie Moss, Caterina Lasome, Dale Downy, Colin Mackenzie, Samer Faraj, and Peter Hu), and from the comments from an anonymous reviewer to an earlier version.

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