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Studying Nurses' Information Flow to Inform Technology Design

by

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Abstract

Information flow within medical environments is ubiquitous and is essential for the coordination and collaboration among spatially and temporally distributed multidisciplinary clinicians for achieving work. Thus, in order to provide the best possible healthcare to patients, nurses working in different shifts must work collaboratively to ensure all the necessary information is communicated so that patient care can be carried on properly.

In this dissertation, I investigate the work practices in use, observing how they are exercised during nurses' information flow, and how they are impacted by new technologies. To gain a good understanding of nurses' actual work practices that have been developed over years of experience, an in-depth observational study was conducted. This study provides a set of benchmark work practices for comparison and contrast when new technologies are deployed. While digital solutions have been replacing paper medical records to provide more consistent, integrated, distributed, and timely sharing of information, current information systems were found to fall short in supporting daily clinical practices due to its fragmented, hierarchical structure. Besides, many technological candidates to replace paper, such as Tablet PCs or PDAs, seem to fall short due to their constrained interfaces, indirect forms of input (mouse and keyboards), inability to share multiple documents concurrently, and failure to support "writing-as-thinking".

In order to apply the knowledge gained through these studies to the development of technologies for a more seamless and less obtrusive fit into the working environment, the results of the observational studies were combined with past literature to inform the development of a conceptual framework for nurses' information flow. This framework is useful for evaluating the impact of new technologies on information flow and for generating new technology designs. This resulted in the development of a technology prototype which I then evaluated through a focus group of practising nurses who indicated promising potential of an integrated charting approach bridging the nurses' use

of paper personal notes and the organizational deployment of digital medical records. The insights gained from this investigation led to the development of a refined set of design guidelines for developing technologies to support nurses' information flow practices.

Publications

Materials, ideas and figures from this dissertation have appeared previously in the following peer-reviewed publications. After each paper, the chapters from which the material is used are noted.

Tang, C., Carpendale, S. and Scott, S. (2010). InfoFlow Framework for Information Flow during Nursing Shift Change. To appear in International Journal of Human Computer Interaction - Special Issue on "Evaluating New Interactions in Healthcare: Challenges and Approaches" (conditionally accepted). (Chapters 5, 6, and 7)

Tang, C., Carpendale, S. and Scott, S. (2009). Supporting Nurses' Information Flow by Integrating Paper and Digital Charting. Proceedings of the European Conference on Computer Supported Cooperative Work (ECSCW) 2009, Vienna, Austria, Sept 7-11. (Chapter 7 and 8)

Tang, C. and Carpendale, S. (2009). A Mobile Voice Communication System in Medical Setting: Love it or Hate it? In Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI) 2009, Boston, MA, April 3-9, pp. 2041-2050. (Chapter 6)

Tang, C. and Carpendale, S. (2008). Evaluating the Deployment of a Mobile Technology in a Hospital Ward. In Proceedings of the ACM Conference on Computer Supported Cooperative Work (CSCW) 2008, San Diego, California, USA, November 8-12, pp. 205-214. Nominated for the Best Paper Award. (Chapter 4)

Tang, C. and Carpendale, S. (2008). Support for Informal Information Use and its Formalization in Medical Work. In Proceedings of IEEE Computer Based Medical systems (CBMS) 2008, Jyvaskyla, Finland, June 17-19, pp. 476-481. (Chapter 4)

Tang, C. and Carpendale, S. (2007). An Observational Study on Information Flow during Nurses' Shift Work. In Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI) 2007, San Jose, California, USA, April 28 - May 3, pp. 219-228. (Chapter 3)

Tang, C. (2006). Designing Technology to Support Information Flow for Asynchronous Co-located Medical Shift Work. In Adjunct Proceedings (Doctoral Colloquium) of the ACM Conference Computer Supported Cooperative Work (CSCW) 2006, Banff, Alberta, Canada, November 4-8. (Chapter 3)

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Dedication

I dedicate this dissertation to my most precious family: Jethro, Zoe and Raymond.

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Chapter 1. Introduction

Information flow within medical environments is ubiquitous and is essential for the coordination and collaboration among spatially and temporally distributed multidisciplinary clinicians for achieving medical work. However, failure of communication, particularly during care handovers, has been reported to be one of the most frequent causes of preventable adverse events to patients (Bates and Gawande 2003, Gurses and Xiao 2006, JCAHO 2007, Weingart et al. 2000). An adverse event is defined as an unintended injury or complication related to healthcare management, rather than to an underlying disease (Baker et al. 2004, NSCPS 2002). Effective communication and information flow has been found to help prevent the occurrence of errors and adverse events in the medical setting, which will in turn benefit patient safety and patient care outcomes (Baker et al. 2004, Bates and Gawande 2003).

Clinicians spend a vast amount of time dealing with a huge quantity of information in the course of providing patient care, through information flow within the same profession (e.g., at shift change), across professions (e.g., during multidisciplinary consultations or when handing a patient over to a different specialty/ward), and between clinicians and patients (e.g., when performing patient consultations). In particular, nurses who work in the frontline handle much of the patient information and help to coordinate the multidisciplinary care among healthcare providers (Allen 1998, Wagner 1993). This research addresses the communication and information flow among nurses in a hospital setting, paying particular attention to the specific communication in the fundamental and important information flow during nurses' daily shift change, which unfortunately has not received adequate attention and technological support. In fact, nurses working in different shifts must work collaboratively to ensure all the necessary information is communicated so that patient care can be carried on properly.

As we move into the 21st century, medical care is making increasing use of technology. Digital solutions have been replacing paper medical records to provide more consistent, integrated, distributed, and timely sharing of information (Harper et al. 1997, Sellen and Harper 2002, Skov and Haegh 2006). However, the handling of medical information is often still a mixture of mental recollection, handwritten notes, displayed information on white boards, verbal reports, digital records and printed documentation. Therefore information exists in different media, making it difficult to maintain consistency among the multimedia information resources. This in turn complicates the information flow in the medical setting. Therefore, my research investigates how information is gathered by nurses, passed on during their shift change, and used throughout a shift.

The goals of this dissertation are to investigate what work practices exist and how they are used during nurses' information flow and to apply this knowledge to the development of technologies for a more seamless and less obtrusive fit into the working environment for improving patient safety by supporting frequent information access and efficient information flow necessary for quality patient care.

This dissertation presents an in-depth investigation of nurses' information flow, paying particular attention to the shift change. I approach this research as a computer scientist but this research involves investigating and bridging a range of perspectives: human-computer interaction, human factors, social factors, and technological applications. My research first investigates the work practices currently taking place in the nurses' work environment: how their work is organized, how it is carried out, how it is managed, what intermediary artefacts are used and how it can be supported by technology. I also investigate the impact of technology deployments on the information flow practices as a means to understand how technology can be designed to better support or enhance current practices.

The motivation for this research was derived from the following premises:

1. *Medical practitioners, specifically nurses, would benefit from a system developed to enhance information flow practices by facilitating more effective and efficient collection, use, and dissemination of information.*
2. *Saving time in the area of information flow activities will leave more time for nurses to spend on providing direct patient care.*
3. *The study of nurses' information flow practices will provide useful lessons which may apply to enhance information flow in other professions such as physicians' and other multidisciplinary information flow in the medical setting.*
4. *The knowledge gained from an information-critical domain of healthcare provides a good potential for application to other similar information-critical or less-information-critical settings.*

The remainder of this chapter discusses the scope and overall research context of this dissertation, describes the problem and goals of the research in more detail, explains the methodological approach used in this research, and provides an overview of the remaining chapters in this dissertation.

1.1 Background and Research Context

This research investigates nurses' information flow with emphasis on the shift change period. Figure 1 illustrates how this research fits into the broader context of human-computer interaction (HCI). HCI is concerned with studying humans interacting with computing technologies, and designing, prototyping/implementing and evaluating technologies to better support human activities for achieving specific goals in a variety of areas, such as work, education or recreation (Dix et al. 1998). Within HCI, my research is contained in Computer-Supported Cooperative Work (CSCW) focusing specifically on the use of computers to support cooperative activities.

The next refinement narrows my primary focus to the domain of healthcare services in which collaboration and coordination among distributed multidisciplinary clinicians are crucial for achieving cooperative work. My focus is further streamlined to nurses' information flow while paying particular attention to the specific time segment of shift change.

Much research on information flow in the healthcare setting has focused on the development of digital information systems, specifically the Electronic Health Records (EHRs), by digitizing the patient database and associated documentation to provide distributed information access with the goal to improve the quality of healthcare (Symon et al. 1996). Despite the benefits of providing more consistent, integrated, distributed, and timely sharing of information (Harper et al. 1997, Sellen and Harper 2002, Skov and Haegh 2006), current information systems were found to fall short in supporting daily clinical practices due to its fragmented, hierarchical structure. For example, clinicians found navigation in the fragmented structure made it difficult to acquire an overview of their patients' condition and was more time-consuming for information retrieval and entry than using paper records (Bossen 2006).

The distributed nature of hospital settings generally entails the need for mobility in order to bring together the right configuration of people, knowledge, resources and

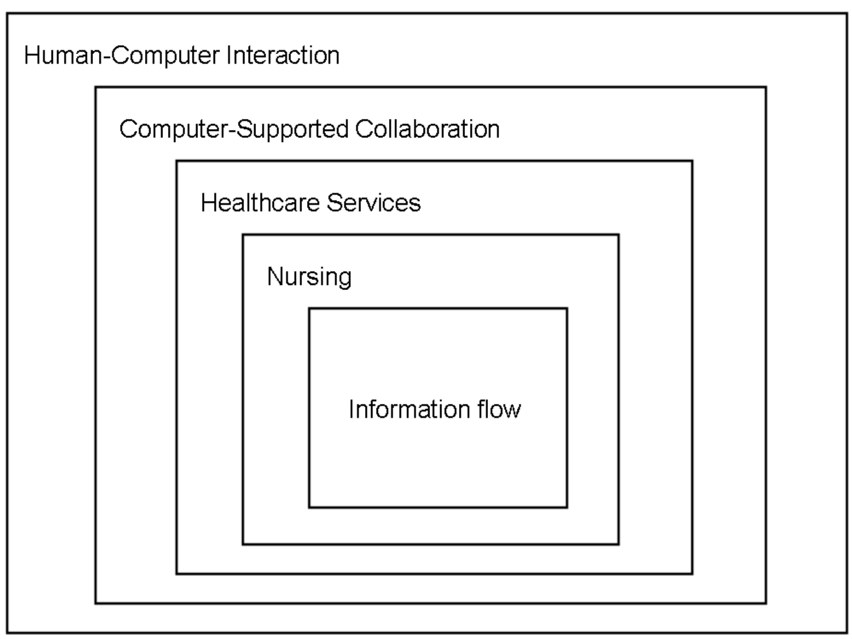


Figure 1.1 Research context

place (Bardram and Bossen 2003, Bardram and Bossen 2005b). Therefore the literature contains a wealth of research on if and how physical information artefacts that were used for coordinating work may be supported by technological solutions. For example, large whiteboards used in a surgical unit to support group discussion and negotiation, and provide an overview of the current operation could be replaced by large digital displays to support these practices by allowing joint manipulation of the display objects and enhancement by users to meet the needs of their dynamic work (Xiao et al. 2001). Another study that investigated how a network of physical artefacts that supported nurses' work revealed that technologies could be designed to allow information to decouple from its representation so that different views of the same information could be displayed to meet different needs, tasks, working contexts and settings (Bardram and Bossen 2005a).

Studies of paper artefacts in work contexts revealed various difficulties in designing technologies to imitate or replace the unique affordances offered by regular paper, such as its flexibility and portability. Many technological candidates to replace paper, such as TabletPCs or PDAs, seem to fall short due to their constrained interfaces, indirect forms of input using mouse and keyboards, the inability to share multiple documents concurrently (Heath and Luff 1996, Harper et al. 1997), and remarkably their failure to support "writing-as-thinking" (Ash et al. 2004). In other words, one of the most valuable characteristics of regular pen and paper artefacts is their support of clinicians' cognitive processes, e.g., in determining a differential diagnosis (Ash et al. 2004). These studies strongly pointed to the need to design technologies which, when replacing regular pen and paper artefacts, do not lose the often unrecognized valuable properties of pen and paper (Heath and Luff 1996, Harper et al. 1997).

Shift change is a crucial element of the continual information flow between various staff members across shifts and is thus essential to the continuity of patient care (Currie 2002, Strople and Ottani 2006). Information communicated during shift change provides incoming clinicians with "the picture of the ward" (Bardram and Bossen 2005b, Harper and Hughes 1993). However, communication failure and missing information during shift change have been found to be contributing or causal factors in many clinical mishaps (Currie 2002, ACSQHC 2005, Strople and Ottani 2006) such as *"wrong treatment, delays in medical diagnosis, life threatening adverse events, patient complaints, increased health care expenditure, increased hospital length of stay and a range of other effects that impact on the health system"* (ACSQHC 2005).

Previous studies on medical shift change mostly focused on a specific aspect of the process. Some studied the benefits and drawbacks of a particular handover practice such as bedside handover, audio-taped handover, handover conference, written and computerized shift reports, and examined if one handover style should be replaced by another (Currie 2002, Strople and Ottani 2006). However, they did not find any particular practice as superior. Some investigated the content of information communicated and the ways to improve the handover efficiency (e.g., Baldwin and McGinnis 1994, Berg and Goorman 1999, Hardey et al. 2000, Strauss et al. 1985). From these studies, I have gained considerable insights into the processes and challenges for effective shift change.

However, these studies did not take into consideration how the information flow practices at shift change fit into the continual information flow during their shift work and how that may be supported by technologies. For example, many studies have identified that individual nurses created and used a paper artefact for the collection of information during shift change and for use in their shift work (Allen 1998, Fitzpatrick 2004, Hardey et al. 2000). Mobile technological devices (e.g., PDAs) were thus introduced to replace this "old-fashioned" information resource to provide information access and note-taking at the point of care (e.g., Silva et al. 2006). Yet, these devices generally lack the valuable, perhaps unrecognized, affordances that pen and paper artefacts offer for supporting clinicians' work practices (Harper et al. 1997, Lu et al. 2005, Silva et al. 2006).

Therefore, my research takes a holistic approach to investigating the dynamics of information flow taking place during nurses' shift change as well as the continual use of information throughout their shifts. My goal is to expand our understanding of these practices and use this understanding to inform the design of technology to enhance nurses' current information flow practices while maintaining valuable work-supporting characteristics that are crucial to their work.

1.2 Problem Statement and Research Hypothesis

The problem addressed in this dissertation is that despite advances in information technology in the last few decades that have considerably changed the way healthcare is delivered, current information technologies do not effectively support nurses' work practices around information flow. This is likely because there have been few studies on investigating the dynamics of nurses' information flow practices and consequently insufficient information to inform the design of relevant and supportive technology.

Whereas EHRs have increasingly replaced or supplemented paper-based documentation to allow quick information access across distributed locations, their hierarchical structure makes information access and entry cumbersome and time-consuming. Similarly, while mobile digital devices are prevalently deployed in hospital settings to allow mobile access to medical information, these devices rarely afford an intuitive mode of interaction for accessing information at points of care (Cohen and McGee 2004, Lu et al. 2005). Thus many clinicians persistently rely on paper personal artefacts (e.g., personal notes written on a note pad or a note sheet and carried around) that they informally use in the course of their work (Hardey et al. 2000, Fitzpatrick 2004, Tang and Carpendale 2007a). In fact, the importance of paper personal artefacts to support effective information flow in patient care has been well recognized (Allen 1998, Hardey et al. 2000, Silva et al. 2006). Notably, they offer flexibility of use with ongoing tasks (Luff et al. 1992, Mackay 1999, Sellen and Harper 2002, Nomura et al. 2006); newly emerging information can be easily added to these paper artefacts during work in progress. In contrast, the process of updating information via digital devices such as PDAs or Tablet PCs is slower (Silva et al. 2006). As part of their information flow, nurses have to manually transpose the information from their handwritten notes on paper artefact into the digital EHR due to the divide between the paper and the digital medium.

Unfortunately, this process is not only time-consuming but is also prone to errors (Zamarripa et al. 2007).

Given this context, I set myself the research goal to design technological solution to support nurses' actual work practices (Vincente 2004) around their information flow.

As a preliminary step to the design process, a better understanding of the basic existing practices of information flow is needed in order to identify areas where technological support would enhance the work practices. In addition, these basic practices yield a rich set of "original" practices that can also be used as benchmarks for comparison and contrast with the findings from later periods of data collection, e.g., when technological interventions are applied. Thus, the central research hypothesis of this dissertation is that studying nurses' information flow practices *in situ* will inform and facilitate the design and development of technology to enhance information flow and work practices.

1.3 Research Goals

The research hypothesis will be addressed through the following research activities: an in-depth investigation of the basic practices of information flow during nurses' shift change to acquire a thorough understanding of current information flow practices; a focused investigation of the impact of the deployment of a mobile information technology to inform technology design; the development of a conceptual framework that can be used to assess technologies and generate technology designs for supporting nurses' information flow; an investigation of the impact of the deployment of a mobile voice communication technology to identify how existing information flow may be enhanced; the technology designs based on the studies; and the prototyping and evaluation of a technological approach for supporting nurses' information flow. These activities define the six research goals of this dissertation. The following is a more detailed breakdown.

Goal 1. **To acquire a thorough understanding of the basic information flow practices focusing on nurses' shift change.** To achieve this goal, I conducted an observational field study in a local hospital ward, focusing on the basic dynamics of the information flow processes, the information sources involved (including human and physical intermediaries), the information content communicated, and how information transitioned across common and personal information spaces. These information flow practices yield a rich set of "original" practices that can be used as benchmarks for comparison and contrast with findings from subsequent data collections.

Goal 2. **To understand the impact of technology deployment on nurses' information flow.** To achieve this goal, I conducted an observational study at two different time points to investigate short- and long-term phenomena as a result of the deployment of a mobile information technology, "computer-on-wheels". I investigated how the technology supported or impeded current practices focusing on the technical, social, health and organizational issues.

Goal 3. **To explore the possibility of formulating a framework that can be used to assess and generate technology ideas, based on the findings from Goal 1 and past literature.** To achieve this goal, I conducted detailed analysis of the field notes and the personal artefacts collected from the study in Goal 1, together with distilment of related literature, to identify important factors and their impact on the information flow. I used this knowledge to develop a conceptual framework, InfoFlow Framework, which can be used to describe existing information flow, to aid in the analysis of data for assessing technology in use, and to inform the design of new technologies for supporting nurses' information flow.

Goal 4. **To demonstrate the applicability of the framework by using it to assess the impact of newly deployed technology on information flow.** To achieve this goal, I conducted an in-situ qualitative field study to investigate how a mobile voice communication system impacted nurses' information flow practices. The data analysis was structured with the framework factors represented in a fish-bone diagram to provide an overview visualization of the technology deployment and to help focus the analysis of the phenomena impacted by the framework factors.

Goal 5. **To further demonstrate the utility of the framework by using it to generate new technology design.** To achieve this, I used the framework to generate a set of design goals which were then used to guide the development of technology design for enhancing nurses' information flow. The basis of the design goals lies in the importance of supporting work practices that nurses have established and adjusted through their practical experience on the job, which were identified in the field studies in Goals 1, 2, and 4.

Goal 6. **To prototype and evaluate a technological approach for supporting nurses' information flow and using this experience to refine the design guidelines for similar systems.** To achieve this goal, I identified a salient work practice phenomenon that was common in the studies in Goals 1 and 2. This work practice was selected because it was found to be crucial for facilitating nurses' task accomplishment while at the same time, was inefficient. Thus it appeared to be a potential area for technological support. I prototyped a technological approach identified in Goal 5 integrating paper and digital media for supporting the work practice. I also conducted a focus group evaluation to examine the technology design on its potential to enhance nurses' information flow, resulting in a refined set of guidelines for designing and developing technologies for supporting nurses' information flow.

1.4 Methodological Approach

A qualitative inquiry conducted in a naturalistic real-life setting using mixed traditional methods -- observations, participant interviews and examination of artefacts -- was chosen to investigate information flow during nurses' shift change in a hospital setting. The naturalistic setting, in contrast to a laboratory setting, allows a holistic approach which promises a richer quality of data collected and offers insights for an enhanced understanding of the practice realities and subtleties in context (Adler and Adler 1994).

Field studies allow us to collect evidence of the "lived work" of the setting (Hartswood et al. 2003) that include episodes from real life (Hayes and Abowd 2006) and issues that may remain unnoticed using other study methods (Balka and Kahnamoui 2004, Wilson et al. 2007). Therefore, qualitative field studies were deemed the best method in providing a meaningful guide to inform technology design that can most likely support work practices (Ash et al. 2004, McGrath 1995, Strauss 1987, Strauss and Corbin 1990).

My research goals align with the following goals of qualitative studies (Maxwell 2004, p.22-23).

- "Understanding the particular *context* within which the participants act, and the influence that this context has on their actions",
- "Identifying *unanticipated* phenomena and influences, and generating new, grounded theories",
- "Understanding the *process* by which events and actions take place".

Moreover, qualitative inquiries, or field studies, provide the opportunity for researchers to acquire knowledge of the domain and to develop common, shared knowledge and language with the participants (Kristensen et al. 2006). In contrast to a predetermined and rigidly structured research design as in controlled experiments (McGrath 1995), the naturalistic character of field studies encourages the qualitative researcher to "analyze as he goes along both to adjust his observation strategies, shifting some emphasis towards those experiences which bear upon the development of his understanding, and generally, to exercise control over his emerging ideas by virtually simultaneous checking or testing of these ideas" (Marshall and Rossman 1999, p.152). Also, field studies may provide evidence of negative instances which will in turn lead to further data collection and analysis and strengthen the interpretation of the real-life setting (Marshall and Rossman 1999, p.152).

However, a potential weakness of direct observation is its potential intrusiveness, i.e., the potential impact of observation on the behaviour and performance of participants being observed. This type of phenomenon has been called the reactive or Hawthorne effect (Patton 1990). To minimize this aspect of qualitative research it is best for researchers to remain as unobtrusive as possible during the observations. Moggridge (2006) suggested that researchers should become a "fly on the wall" so that no one notices. If a researcher manages to "fade into the background" over time, the impact of the researchers' presence on participants' behaviour and performance should be minimal (Carpendale 2008, Lally 1999).

Qualitative data are generally complex and the raw data themselves may have no inherent meanings (Drury 1995). Thus their analysis "draws on both critical and creative thinking" (Patton 1990, p.434) to bring "order, structure, and interpretation to the mass of collected data" (Marshall and Rossman 1999, p.150). Open coding from the grounded theory research approach was used for the analysis of the collected data throughout the research process. This coding method begins with breaking up the collected data into events, happenings, objects, actions, and interactions according to a set of loosely defined descriptors or codes derived from an initial understanding of the collected data. Then through iterative comparison for similarities and differences, the data are grouped under more complete and more focused coding scheme (Strauss and Corbin 1990).

1.5 Results and Contributions

This research builds on previous literature on the practices pertinent to general information flow in healthcare settings and also more specific information flow during shift change in high-reliability domains including healthcare. It contributes expanded understanding, original ideas, knowledge, and practices to the fields of Human-Computer Interaction (HCI), Computer-Supported Cooperative work (CSCW) and healthcare services research. There are six major contributions from this research.

- It identifies the basic dynamics, practices, and information media which facilitate information flow during nurses' shift work, including the shift change period. Most previous research focused on a few aspects and studied the process of shift change as a single activity via a single medium, e.g., verbal shift handovers or written shift reports. The results from previous research have not been articulated to inform the design of technologies to support the information flow.

- It identifies both short-term and long-term impacts of the deployment of a mobile information technology on nurses' information flow practices with respect to technical, social, health and organizational issues. It also identifies factors explaining the adoption, or non-adoption, of the new technology. This technology was compared with the "old-fashioned" paper artefacts that are currently relied upon as bedside information resource. The findings helped point to design directions for technological solutions to facilitate the information flow.
- It develops a conceptual framework for nurses' information flow. This framework can be used to describe information flow, assess new technology in use, and generate technology designs to support nurses' information flow.
- It demonstrates that the conceptual framework can be used to generate a set of effective communication strategies which are then used to guide the assessment of the impact of newly deployed technology on information flow.
- It demonstrates that the conceptual framework can be used to develop a set of design goals which are then used to generate technology design to support nurses' information flow.
- It demonstrates that a technological scheme can be developed to support nurses' practices of information flow. The qualitative focus group findings demonstrate that qualitative research that involves in-depth investigation of basic practices for information flow and subsequent investigation of the impact of new technologies can result in a supportive system design for current work practices around information flow.

In addition, several aspects of the approaches used in the studies conducted in this research proved particularly valuable and can be generally applied in studies for evaluating new technologies. The following insights gained both confirm qualitative research practices and are recommended for future studies to consider.

First, through in-depth investigation to establish a baseline for future studies provides important benchmarks for evaluating new technologies (e.g., Wallace and Lamaire 2006). Second, it is important to evaluate against established objectives yet also remain receptive to discovering unexpected outcomes of new technology (e.g., Wilson et al. 2006). Third, the use of a triangulation of research methods shows clear benefits to study the research problems. For example, direct observations help to identify phenomena that participants may not report (Alder and alder 1994, Drury 1995) whereas interviews are useful to determine participants' perceptions and explanations of processes (Dix et al. 1998 pp. 432). Fourth, conducting data collection at different time frames helps uncover short- and long-term phenomena (Denzin 1989 pp. 237). This in turn helps direct resources to improving desired issues. Fifth, examining artefacts collected at different times provides a convenient way to identify how they are actually used (Denzin 1989 pp. 237, Tang et al. 2009) since it is generally time-consuming and labour-intensive to follow participants in order to find out how they use artefacts. Finally, an analysis method that combines framework-based communication strategies and fish-bone representation (Ishikawa 1960s) was developed in this research for investigating impact of new technology (Chapter 6). These practices and approaches will be discussed in more detail in the remaining chapters.

1.6 Organizational Overview

The organization of the remaining chapters reflects the qualitative research methodological approach of this work by first presenting the study that was originally performed to explore the basic dynamics of information flow during nurses' shift change and a summary of the findings for informing technology design for supporting the specific information flow during nurses' shift change. However, the richness of the findings from this study made it an ideal candidate to be served as benchmarks for comparison and contrast with findings collected in subsequent opportunistic studies when new third-party technologies were introduced. The understanding gained from these studies led to the design of a technological scheme to facilitate nurses' information flow, which was then prototyped and evaluated. Figure 1.2 shows an overview of the studies conducted in this research indicating the information and communication technologies available at the time of each study. Vocera is a mobile voice communication system that will be described in Chapter 6. Patient care summaries are abbreviated paper medical records that were printed at the beginning of each shift for use during the shift. TDS and SCM are both digital healthcare information systems. TDS is a Disk Operating System (DOS) based information system that was first built in mid 1960s whereas SCM (Sunrise Clinical Manager) is a hierarchically-structured Windows-based information system that has the ability to connect multidisciplinary caregivers involved in a single patient's care.

Chapter 2 sets the foundations for this dissertation by first presenting a brief overview of shift change in other high-reliability domains, then a review of research conducted to investigate shift change in the hospital setting, followed by previous

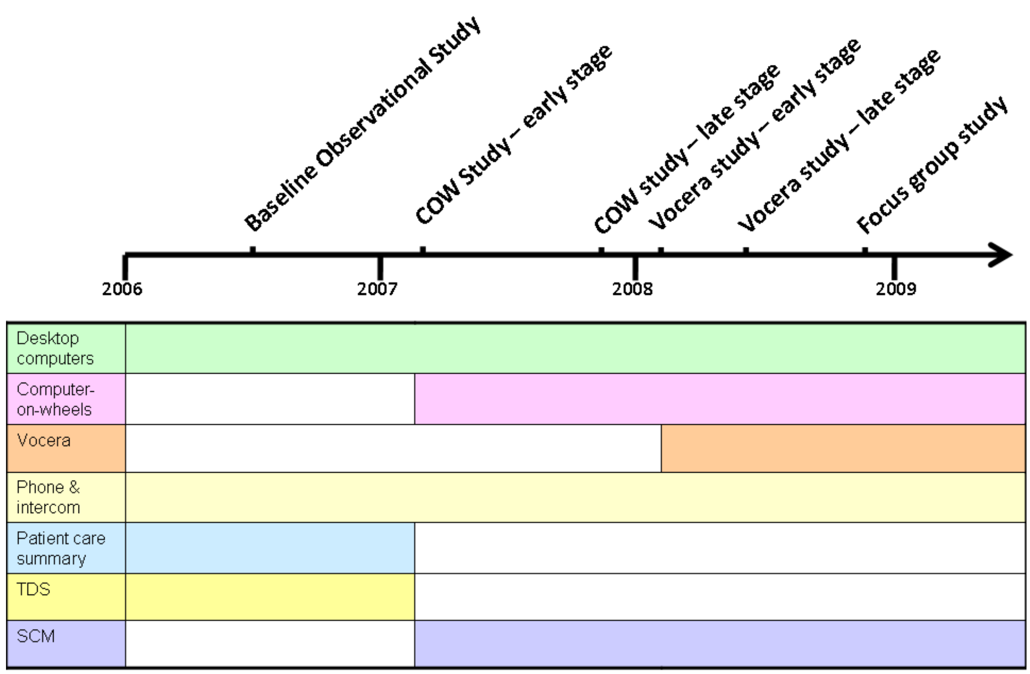


Figure 1.2 Timeline of the studies conducted in this research indicating the computing technologies available at the time of the studies (Vocera – a mobile voice communication system, Patient care summary –abbreviated electronic health record in paper, TDS – a legacy electronic health record, and SCM – a new electronic health information system)

research that investigated important characteristics of medical settings as pertains to the information flow. This review takes a multidisciplinary approach, drawing in relevant findings from the human-computer interaction, computer-supported cooperative work, healthcare services, and human factors literature.

Chapter 3 presents the first observational study of this dissertation. The focus of this study was on understanding the basic dynamics of information flow during nurses' shift change. This study identified the processes, the information spaces, the artefacts, the media, and the information content involved in the shift change. This study highlighted the importance and personalization of paper personal notes that played a crucial role in nurses' shift work. Its rich findings were later used as comparison benchmarks with subsequent studies described in Chapter 4 and 6.

Chapter 4 describes a field study conducted at two time frames to investigate the impact of the deployment of a mobile information technology, computer-on-wheels, on nurses' information flow. The longitudinal study design helped identify both short- and long-term phenomena resulting from the technology deployment. The findings could help direct resources to improving specific issues. This chapter ends with several suggestions for designing technologies to support nurses' information flow.

Chapter 5 presents a framework that can be used to assess and generate technology designs for supporting nurses' information flow. This framework is developed from the findings from the baseline study described in Chapter 3 and distilment of past literature. It consists of six inter-related factors that were found to be important to the information flow. A list of questions centred on the framework factors is provided to serve as triggers when describing information flow, assessing new technologies, or generating technology design.

Chapter 6 describes an observational study to investigate the impact of the deployment of a mobile voice communication system, Vocera® (http://www.vocera.com), on nurses' information flow. The analysis of this longitudinal study was based on a set of observed communication strategies derived from the framework factors. The findings were then organized as pertain to the framework factors in a fish-bone diagram to provide an overview visualization and a focused assessment of the information flow as impacted by the new technology. Both positive and negative impacts that were salient in the analysis were discussed and several design guidelines were proposed.

Chapter 7 first presents a set of design goals generated from the framework, based on findings from the field studies described in Chapters 3, 4, and 6. These design goals were then used to inform technological design for supporting nurses' information flow.

Chapter 8 describes a prototype of the technology proposed for supporting a salient work practice crucial to nurses' information flow. An evaluation of the prototype was conducted through a focus group study. Feedback and suggestions for improvements were obtained, indicating its potential to support nurses' information flow practices in the dynamic work environment.

Chapter 9 concludes the dissertation by indicating how the research goals have been addressed by this work. The contributions of this work are then summarized. Finally, the chapter discusses possible future research directions that could further the research ideas developed in this work.

Chapter 2. Background

Continuous, uninterrupted operation is crucial to a wide range of work environments ranging from patient safety in a hospital, to smooth operation of chemical processing plant, to safe operation of a space shuttle mission. The fact that no human can work continuously without rest and that operations cannot be entirely automated via technology makes shift work inevitable for achieving such continuous operations. Thus, shift change plays a crucial role to ensure continuity of the operation across shifts.

Previous studies on shift change mostly focused on how information was handed over to the incoming operator (e.g., Bentley et al. 1992, Bertelsen and Bodker 2001, Grusenmeyer 1995, Harper and Hughes 1993, Patterson and Woods 2001). Thus shift change is commonly known as shift handover or handoff. These terms literally refer to "information push" (De Haan 2000) by the outgoing operator to the incoming colleague. However, many studies actually revealed that incoming operators also pull information from a range of information artefacts or simply by observing to acquire a better understanding of the operation (e.g., Grusenmeyer 1995, Patterson and Woods 2001). Therefore, I prefer using "shift change" to describe *the process in which information flow takes places during the shift transition between outgoing and incoming operators*.

Shift change practices vary considerably across domains and may also be different across organizations, departments and work teams within the same domain. Practices range from face-to-face communication between two persons involving minimal information exchange to highly complex practices involving multiple people of different professions and spatially distributed information resources.

In the medical setting, communication and information flow is ubiquitous and accounts for a substantial part of healthcare practitioners' daily routines, encompassing interactions in varying contexts and information sharing across temporal and spatial dimensions (Bardram and Bossen 2005a, Bossen 2002, Schmidt and Bannon 1992). Yet, communication failure has been found to be the most frequently cited root cause, 65-70%, of adverse events by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO 2007). Besides, communication that occurs in the process of passing patient-specific information from one caregiver to another, from a team of caregivers to another team, from one healthcare organization to another, etc., has been identified to be high-risk with respect to patient safety (JCAHO 2007).

Therefore, my research initially focused on information flow during nurses' shift change in hospital settings. However, as my research progressed, it became clear that shift change is integral to the continual flow of information. Thus my research extends to also study how information gathered during shift change is used throughout nurses' shifts and my goal is to design technologies to support that information flow.

Before effective technologies can be developed to support information flow in hospitals, it is useful to first understand how shift change has been successfully achieved in other high-reliability domains. Besides, as shift change is a crucial part of continual information flow in hospital shift work, understanding general information flow in the hospital settings will be an asset. Therefore, to provide a general understanding of this broader context, Section 2.1 first reviews shift change in critical settings. Section 2.2 focuses on shift change in hospitals, and Section 2.3 provides a characterization of hospital work. I also highlight the technological support currently available in each domain/setting.

2.1 Shift Change in High Reliability Settings

This section presents shift change taking place in high reliability settings, i.e. "organizations with zero tolerance for error as even the slightest mistake can have catastrophic consequences" (Lutters and Ackerman 2002). Examples include space shuttle mission control center, air traffic control room, nuclear power plant, offshore petroleum facility and hospitals. Medical settings will be discussed in later sections. This section focuses on other high-reliability settings to review the goals of shift change (Section 2.1.1), typical phases of shift change (Section 2.1.2), example incidents contributed to or caused by errors during shift change (Section 2.1.3), documented causes for shift change errors (Section 2.1.4), strategies that can facilitate shift change effectiveness (Section 2.1.5), and technological support for shift change (Section 2.1.6).

2.1.1 Goals of shift change

The primary objective of shift change is to ensure smooth continuity of operations from one shift to the next. However, depending on the nature of the setting, the focus of shift change slightly varies. Examples include preventing any breaks in the production process (e.g. paper mill plant - Grusenmeyer 1995), ensuring the operation will continue as if the operator had never been replaced (e.g. space shuttle mission control centre - Patterson and Woods 2001), striving for a complete transfer of information with a minimum amount of workload (e.g. air traffic control in USA - FAA 2008), and providing the controllers a common ground to '*get the picture*' and acquire a '*mental model*' of the current status of the operation (e.g. UK air traffic control - Clark and Brennan 1993, Harper and Hughes 1993). A mental model is an internal representation of some aspects of the world and its processes. Via mental models it is possible to develop an understanding of factors such as a setting and the relationships between various aspects of the setting which help shape behaviour and guide the approach taken to solving problems and carrying out tasks (Wikipedia).

Based on thorough literature reviews on adverse events in various industrial and medical settings where failures of communication or misunderstanding at shift change were identified as causal or contributory factors, Lardner (1996) defined shift change as "*to achieve accurate, reliable communication of task-relevant information across shift* *change, thereby ensuring continuity of safe and effective working*". This definition has since been frequently cited in publications.

2.1.2 Shift Change Process

Standard Operating Practice (SOP) is established in many high-reliability organizations to guide how shift change should be conducted in order to achieve the desired outcome, i.e. to achieve accurate, reliable communication of task-relevant information across shift change, thereby ensuring continuity of safe and effective operation. Although shift change is conducted differently across settings, it is generally composed of three phases: pre-handover, handover meeting and post-handover (Grusenmeyer 1995). The degree of structuredness of the shift change process appeared to be proportional to the level of reliability of the organization. In addition, shift change taken place in settings without a SOP usually relies on the experience of relevant personnel to ensure smooth continuation of the operation.

Pre-handover. Incoming personnel acquire information by observing the operation (Patterson and Woods 2001, FAA 2008, Harper and Hughes 1993), reading relevant documentation (e.g., logs) and information displays (e.g., Figure 2.1) (Grusenmeyer 1995, Patterson and Woods 2001, FAA 2008, Harper and Hughes 1993), and listening to ongoing communications (Patterson and Woods 2001, FAA 2008, Harper and Hughes 1993) to build a mental model of the current operation while outgoing personnel continue the ongoing operation. For instance, the SOP stipulated by FAA (Federal Aviation Administration) requires incoming air traffic controllers to follow a detailed checklist to review various aspects of the operation before they can indicate to the outgoing flight controllers that the position has been previewed and they are ready for the handover meeting (FAA 2008).

Figure 2.1 Large displays in space shuttle mission control room to provide at-a-distance view (Patterson et al. 1999, pp. 355)

In an UK air traffic control room, the controllers spent 5 to 10 minutes watching over the shoulders of their predecessors to "build up a picture" both generally and specifically of what was happening in the sector before taking over the position (Harper and Hughes 1993). In other settings where operational information was not readily available for review, outgoing personnel would then construct a detailed summary of the activities and plans achieved, altered and unfinished in the previous shift that needed to be transferred to the next shift (Grusenmeyer 1995). Thus, pre-handover is important for incoming personnel to acquire a basic set of knowledge so that they are prepared for the handover meeting in which questions and topics specific to the activities to be performed in their shift will be addressed and discussed.

Handover meeting. Handover meeting is vital to shift change in high-reliability settings as it allows outgoing and incoming personnel to verbally check for shared understanding of the operation and subsequent plan of activities for 'building the picture' of the operation (Grusenmeyer 1995, Patterson and Woods 2001, FAA 2008, Harper and

Hughes 1993). These handover meetings were always conducted where relevant equipment was located so that needed information was readily available.

Some handover meetings also involved multiple sub-phases to ensure information was accurately transferred. For example, handover meetings in the space shuttle mission control room began with a verbal one-on-one meeting between outgoing and incoming controllers of the same position. Both controllers asked questions of each other to clarify, to check for understanding and to ensure all needed information had been discussed. Then team communication was conducted over a voice loop which allowed distributed controllers of different positions to remain at their console while outgoing controllers listened in to the communication and made necessary corrections and clarifications over the voice loop (Patterson et al. 1999). This allowed all the distributed controllers of various disciplines to check for a shared understanding of the situation following individual position handovers. The multi-stage handover practice enabled incoming controllers to acquire not only the current operation status pertinent to their own position, but also the overall operation of the mission. In this way, they would be better equipped to deal with any unexpected contingent situations that might occur during their shift. Thus handover meetings are vital for incoming operators to acquire a shared understanding and a mental model of the operation.

Post-handover. This phase signifies the end of a shift change as the incoming personnel assume full responsibility and authority for the position they take over. Shift change in critical settings is often characterized by a clearly marked transfer of responsibility and accountability. For instance, controllers in the space shuttle mission control room explicitly transfer responsibility to their incoming colleagues. First, incoming controllers switched from the alternate voice loop to the primary channel. Second, the outgoing Flight Director officially announced the relief of outgoing controllers over the designated voice link. This standard practice made the transfer of responsibility explicit and clear to all personnel involved.

The transfer of responsibility was carried out somewhat differently in the air traffic control room. Incoming controllers verbally informed their outgoing colleagues that they have assumed the duties. But the outgoing controllers would normally oversee the position operation until they were sure that the operation was smoothly overtaken. Then they signed off the position and physically left the control room. In both settings, an explicit transfer of responsibility and authority was employed to signify the end of the outgoing personnel's shift.

2.1.3 Incidents Related to Shift Change

There are many reported cases of accidents related to shift changes in high-reliability domains. Several examples will be used to demonstrate the extent of the possible impact due to communication failure during shift change. In 1983, a large amount of highly radioactive liquid discharge was accidentally released to a public beach in Sellafield, England, by British Nuclear Fuels Ltd, because the written shift report was mis-described across several shifts and eventually misinterpreted by an incoming shift as suitable for discharge to sea, analogous to the outcome of the popular "telephone game" or "Chinese whispers". This contributed to fourteen times more cases of leukemia and non-Hodgkins lymphoma than the national average in a town two miles from Sellafield ten years later (Lardner 1996).

Another accident that occurred in a chemical processing plant in 2005 led to the Texas City fire. The fire was caused by a flooding of an isomerisation column as a result of miscommunication between the night and the day shift operators. This catastrophe led to 15 deaths (Nimmo 2006).

Moreover, the 1988 Piper Alpha disaster which has been regarded as the world's worst offshore oil disaster killed 167 people when an offshore oil platform in the North Sea exploded and then burned. This resulted from the outgoing operator's failure to report that a valve was removed from the backup pump for maintenance, and when the incoming shift workers used it, it exploded (Cullen 1993).

Many other shift-change-related accidents have also been reported in the aviation industry (Parke and Kanki 2008). In fact, a U.S. study found that 25% of all operational errors took place in the first fifteen minutes after shift change in air traffic control centers and terminal radar control facilities (Parke and Kanki 2008). Thus shift change has been identified to be a key area for improvement in many high reliability settings such as air traffic control, space shuttle mission control, nuclear power plants, and health care (Parke and Kanki 2008).

2.1.4 Common Causes for Shift Change Errors

The following common sources of errors have been identified to contribute to or cause adverse consequences in high-reliability settings (Patterson and Woods 2001, Grusenmeyer 1995).

- Incoming operator had an incorrect or incomplete mental model of the operation,
- Incoming operator was unaware of significant data or events, i.e., missing information,
- Incoming operator lacked knowledge to deal with impact from previous events and to anticipate events for performing relevant tasks,
- Incoming operator unwarrantedly altered goals, decisions, priorities or plans without considering the overall operation or consulting other pertinent personnel or documentation.
- Outgoing operator focused on the work that has been carried out rather than on the diagnosis of the situation for anticipating events,
- Handover meeting was hastily conducted resulting in incomplete transfer of information.

2.1.5 Strategies for Effective Shift Change

Studying shift change in a paper mill industrial plant, Grusenmeyer (1995) recommended several important guidelines when conducting shift change. For example, she recommended practising verbal communication between incoming and outgoing personnel, providing aids such as a log book to facilitate the information transfer, avoiding making changes to planned activities during shift change, and clearly identifying the tasks to be performed in the next shift which was later described as a "*predictive diagnosis of the situation*" (Parke and Mishkin 2005).

After a thorough literature review on shift change in a range of industrial and medical settings focusing on incidents where failures of communication at shift change were found to be contributory or causal factors, Lardner (1996) added several strategies for effective shift handover communication. He included the need to communicate via more than one medium (e.g., verbal and written), encouraging feedback at handover for clarification of ambiguity, more thorough handover after a prolonged absence of the personnel, focusing on key information needed for the continual work while minimizing irrelevant information.

Then a set of 21 communication and coordination strategies for shift handoffs was identified from observational studies in four settings with high failure consequences, as indicated by S1 to S21 in Table 2.1 (Patterson et al. 2004). These strategies have since been widely cited in studies on shift change. The settings studied were a space shuttle mission control, two nuclear power generation plants, a railroad dispatch center and an ambulance dispatch center. Face-to-face verbal updating between incoming and outgoing personnel was practised in all the settings. Thus a number of the strategies aimed to improve the effectiveness and efficiency of the verbal interactive updating. Most of these strategies were reported to be consistently used in the four settings. Two thirds of these strategies aimed to help improve effectiveness of shift handovers (S1-S14), half of which also helped improve efficiency (S8-S14). Others aimed to increase access to data (S15-S16), to improve coordination with other pertinent personnel (S17-S18), to enable error detection and recovery (S19-S20), and to delay transfer of responsibility until the operation has been stabilized (S21). Although these strategies were developed from shift change studies in various settings, most of the strategies appeared to be based on and are more applicable for shift change in space shuttle mission control environments. This is likely because the data collected in the other settings were originally collected for other purposes. As a result, several important strategies recommended in previous studies in other settings were not included.

Based on European and American literature on shift change in high-risk domains, Parke and Mishkin (2005) also proposed 22 best practices for effective shift handovers that were to be used as a checklist when conducting handovers. Their recommended best practices showed a high degree of similarity to Patterson et al.'s (2004) communication strategies. They added an important strategy: to promote a safety culture by proactively identifying potential problems before they occur (S28). In another study to investigate shift handover-related incidents by examining NASA Aviation Safety Reporting System (ASRS) maintenance incident reports involving shift change communication problems, Parke and Kanki (2008) proposed checking previous work as a means to stop error propagation (marked "xx" in Table 2.1). Based on these studies, I compiled Table 2.1 which shows an accumulation of these strategies for achieving effective shift change.

Table 2.1 Recommended strategies for effective handoffs (S30 marked xx was recommended in Parke and Kanki 2008)

Strategies	Grusenmeyer 1995	Lardner 1996	Patterson et al. 2004	Parke & Mishkin 2005
S1. Face-to-face update with interactive questioning	x	x	x	x
S2. Additional update from practitioners other than the one being replaced			x	x
S3. Limit interruptions during update			x	x
S4. Topics initiated by incoming as well as outgoing		x	x	x
S5. Limit initiation of operator actions during update	x		x	
S6. Include outgoing team's stance toward changes to plans and contingency plans	x		x	
S7. Read back to ensure that information was accurately received		x	x	
S8. Outgoing writes summary before handoff	x		x	x
S9. Incoming assesses current status	x	x	x	x
S10. Update information in the same order every time			x	

S11. Incoming scans historical data before update	x	x	x	
S12. Incoming receives automatically captured changes to sensor-derived data before update		x	x	
S13. Intermittent monitoring of system status while ‘on-call’			x	
S14. Outgoing has knowledge of previous shift activities			x	
S15. Incoming receives primary access to the most up-to-date information		x	x	x
S16. Incoming receives paperwork that includes handwritten annotations		x	x	x
S17. Unambiguous transfer of responsibility			x	x
S18. Make it clear to others at a glance which personnel are responsible for which duties at a particular time			x	
S19. Overhear others’ updates			x	
S20. Outgoing oversees incoming’s work following update			x	
S21. Delay the transfer of responsibility when concerned about status/stability of process			x	
S22. Clearly identify tasks to perform in the next shift	x			x
S23. Communicate via more than one medium		x		
S24. More thorough handover after prolonged absence		x		x
S25. Focus on key information		x		
S26. Develop communication skills to ensure successful communication		x		
S27. Checklist/guidelines available for handover		x		x
S28. Promote a culture to proactively identify problems				x
S29. Technological support to reduce handover workload		x		x
S30. Check previous work to stop error propagation				xx

2.1.6 Technologies for Facilitating Continuity of Operations

Logs have been widely used to mediate information flow in workplaces. Structured logs served as useful memory aids for information to be included in handovers so that the personnel could focus on relevant information to be passed across shifts while minimizing irrelevant details (Kovalainen et al. 1998, Lardner 1996). In safety critical domains such as air traffic control and space shuttle mission control, flight logs allowed incoming controllers to acquire information on the activities that have taken place and plans that were made.

Large displays, both digital and physical, also play a significant role in coordinating work and allowing incoming personnel to acquire a mental model of current operation which is vital for achieving effective shift change. Controllers in space shuttle mission control room used various digital displays and readings to coordinate the mission control (Figure 2.1). Meanwhile, air traffic controllers were repeatedly found to rely on the use and manipulation of physical paper flight strips on a large display board to coordinate and assess current and upcoming events (e.g., Figure 2.2) (Bentley et al. 1992, Mackay 1999, Nomura et al. 2006). These large displays provide a shared at-a-distance view for collaborators to discuss and negotiate for a joint understanding of the operation important for shift change.

New technologies often engender new work practices and thus may require an adjustment to existing SOP (Balka and Kahnamoui 2004). For example, new technologies deployed for coordinating work in a nuclear power plant were found to have altered controllers' shift change practice. With the use of new digital technologies, controllers received updates at their consoles whereas before, controllers had to physically walk down the control panels to familiarize themselves with the operation from the old analogue controls (Vicente et al. 2001). While both practices aimed for the same purpose to acquire a mental model of the current operation, advances in technologies often entailed changes to the SOP.

2.2 Shift Change in Hospitals

Similar to other high-reliability settings, shift change in hospitals plays a fundamental role in ensuring patient safety through continued operation, reduced errors and enhanced patient outcomes (Keenan et al. 2006). This is achieved when information communicated during shift change provides incoming clinicians with "the picture of the ward" (Bardram and Bossen 2005a, Harper and Hughes 1993). However, shift change is regarded as a most critical point in hospital care and as a 'clinical brain dump' within a brief time period (Keenan 2007). Also, studies have shown that the risk of breakdown in information flow is significantly increased at and soon after shift change and that the consequences can be catastrophic (Lardner 1996, Patterson and Woods 2001). Thus effective shift change would make a vital contribution to safe patient care (Currie 2002, Wears et al. 2003).

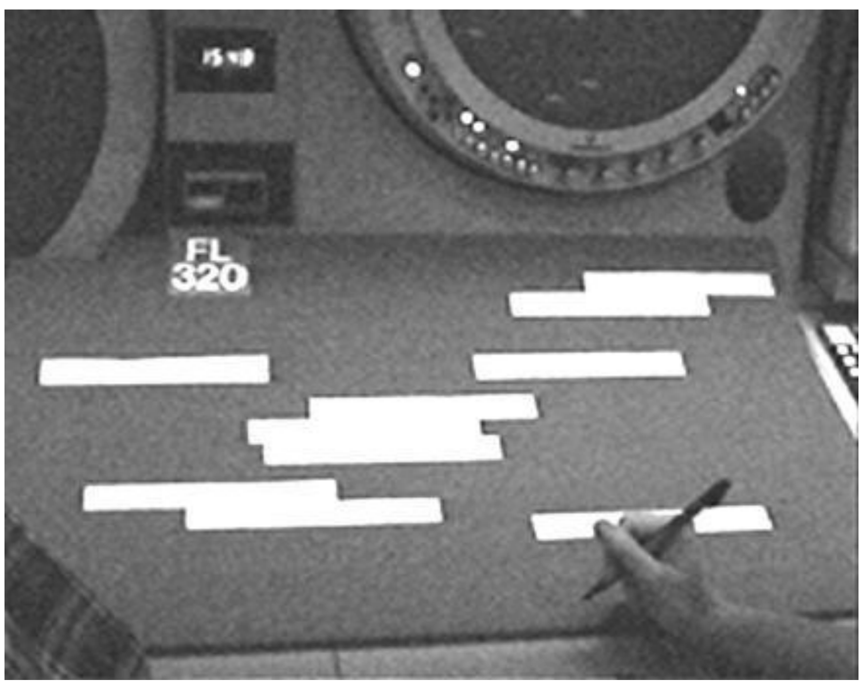


Figure 2.2 Paper flight strips used to reflect the geographic position of aircrafts in the sky (Mackay 1999, pp. 335)

In this section, I will review several identified functions of shift change that were not documented in other high-reliability settings (Section 2.3.1), styles of shift handover (Section 2.3.2), information content (Section 2.3.3), failure of communication (Section 2.3.4), and quality of shift change in hospitals (Section 2.3.5).

2.2.1 Functions of Shift Change

In other high-reliability domains described in Section 2.1, information and responsibility transfer across shifts was the goal of shift change documented in literature. Yet, there were other important functions of shift change consistently identified in medical settings.

In hospitals, an accurate and reliable *transfer of information and responsibility* across shifts is still the primary function of shift change. It provides an opportunity for nurses in consecutive shifts to communicate important medical information, such as a patient's diagnosis, vital signs, diagnostic tests, and restrictions for planning patient care by developing treatment plans, prioritising and allocating activities for the shift so that patient care can be continued (Alvarado et al. 2006, Currie 2002, Kerr 2002, Lamond 2000, Riegel 1985, Sexton et al. 2004, Strople and Ottani 2006, ACSQHC 2005).

Shift change provides an opportunity for *rescue and recovery* from incipient failure. This is possible because situations are reviewed by "fresh eyes" of the incoming shift when outgoing and incoming clinicians interactively communicate and work together to reach mutual understanding and shared reasoning (Perry 2004, Wears et al. 2003, Wilson et al. 2005, Wilson et al. 2007).

Shift change serves a *social* function by providing an opportunity for nurses to casually interact and to catch up with their colleagues. These social interactions were found to be important to increase group cohesion and team spirit, enhance a culture of shared values, and provide a venue for staff catharsis (Bourne 2000, Kerr 2002, Lally 1999, Riegel 1985, Sexton et al. 2004, Wilson et al. 2005).

Shift change provides an opportunity for *education*, for novice and junior clinicians to learn from their experienced and senior colleagues (Allen 1998, Kerr 2002, Lally 1999, Wilson et al. 2005).

Finally, shift change is used for meeting *organizational* agenda such as staff management and patient care documentation for the purpose of meeting legal requirements (Allen 1998, Kerr 2002, Lee 2006). However, some studies found the nursing records so defence-oriented that they barely represented the patient care that has been delivered (Hardey et al. 2000, Allen 1998).

2.2.2 Shift Change Process

As opposed to the relatively structured phases of pre-handover, handover meeting and post-handover found in other high-risk domains, shift changes in hospitals have been criticized for lacking a formal structure and guidelines on how shift change should be conducted and what information should be communicated (Allen 2004, Alvarado et al. 2006, BMA 2004, Cheah et al. 2005, Sexton et al. 2004, JCAHO 2007). In fact, shift change varies considerably across teams, wards, departments, and hospitals. For example, in some settings, no handover meeting was practised. Thus information could only be acquired from official documentation (Sexton et al. 2004).

To set the scene for my research, I focus the following discussion on nursing shift change. Several commonly practised activities: face-to-face handover, team handover, written/typed handover and audio-recorded handover, are discussed (Currie 2002, Munkvold et al. 2006a, Strople and Ottani 2006, Sexton et al. 2004, Riegel 1985). Each style has specific benefits and drawbacks that could influence a clinician’s ability to plan patient care (Dowding 2001); no one method was found to be superior to the others (Currie 2002, ACSQHC 2005, Strople and Ottani 2006). In fact, these styles were criticized as being ineffective, and could contribute to negative patient outcomes (Strople and Ottani 2006). Therefore, there has been increasing trend to look for technological solutions to support shift change.

Face-to-face Handover. Face-to-face handover is usually conducted at either bedside or a location away from patients, typically at a nursing station. Bedside handover is favoured in patient-centred care in which patients can take an active role in their own care. However, bedside handover is usually time-consuming and may also intimidate patients (Currie 2002). Verbal handover that takes place at a nursing station provides confidentiality while incoming nurses can receive information all at once and important medical documentation is easily accessible. Thus it reduces the length of handover. As anticipated, a combination of handover at bedside and at nursing station could more effectively ensure complete and accurate information transfer across shifts (Currie 2002, Hardey et al. 2000).

Face-to-face handovers offer rich two-way verbal communication for questions and clarifications, but may result in excessive overtime due to lengthy reports which may also contain inadequate and inconsequential data (Baldwin and McGinnis 1994). Besides, these handovers usually do not allow nurses to hear updates of other patients on the ward. Thus this could result in a loss of situation awareness for other patients, making it more difficult to accept temporary responsibility, e.g., in lunch breaks, and to quickly respond to acute events (Patterson 2005).

Team Handover. Team handover is usually conducted through a proxy (e.g., charge nurse), dominated by one-way communication, either through reading out a prepared report or playing a taped report recorded in a tape-recorder or Dictaphone. These reports were collated from team colleagues, official documents and personal notes before the handover (Kerr 2002). This type of handover discourages incoming personnel from asking questions (Kerr 2002, Patterson 2005). Also, patients' requests during shift change would have to be delayed until the end of the handover as it often takes place at a location away from patients (Patterson 2005). This handover style, nevertheless, is cost-effective in terms of time.

Written/Typed Handover. Outgoing nurses may prepare a written or typed report for incoming nurses to read. These written reports were found to result in more accurate and thorough nursing documentation (Sexton et al. 2004). Without the rich two-way verbal communication, written handover alone does not allow incoming nurses to ask for clarification on issues that they are unsure. The obvious benefit is the temporal flexibility that incoming nurses can enjoy as they can review the report at their own time and pace.

A variation of written/typed reports can be found in a telephone-based handover system, Nurse Communicator, which allowed outgoing nurses to record patient information throughout their shift for incoming nurses who could then access it any time (Hewitt 1997).

While the abovementioned practices for conducting nursing handover meeting were prevalent in hospitals, shift change often involves other activities that are not as well-defined. For example, nurses may also need to acquire information available in other artefacts, such as patient charts and electronic health records, in order to carry out adequate patient care. Yet, it is often difficult to determine how much and what patient information should be reviewed from the documentations as this highly depends on individual patient's illness and their progress, as well as the knowledge and experience of individual nurses. Moreover, although the ideal case is to immediately document newly emerged information in proper information sources, the dynamic and time-pressured medical work often makes it impossible. Instead, this updating activity, as generally perceived as secondary to actual patient care, is often only conducted near or at the end of a shift. Therefore incoming nurses would have to adjust their information seeking activities in order to build an accurate mental image of their upcoming shift work. The transfer of responsibility across nursing shifts is also often not as explicit and clear as in other high-reliability domains. For instance, outgoing nurses may still be providing patient care even after the handover meeting. Such overlap is quite common particularly during busy times or when the outgoing nurse had already started a particular patient care procedure that spanned across the shift change.

2.2.3 Information Content

Studies revealed that information content communicated during shift change varied considerably across the styles of handover and the settings. Some studies indicated that most of the information communicated in verbal reports can also be found in existing information artefacts, so the verbal contents were mostly irrelevant, repetitive, speculative or even causing confusion (Patterson 2005, Perry 2004, Sexton et al. 2004). Thus it was recommended that more effort should be placed on keeping documentations up-to-date and concise rather than on the redundant verbal handover (Sexton et al. 2004). However, other studies found that verbal handover contains information such as the patients' psychological states and social situations which either was not found or was fragmented over the official documents (Allen 1998, Wilson et al. 2005). Besides, the controversial judgemental comments towards patients are usually only found in verbal reports (Lamond 2000).

Information content communicated during shift change also depends on the nature of the specific medical setting (Dowding 2001, Lamond 2000). For example, patients' social information is not as important in an emergency ward setting as in a general clinical setting where social information may help with, e.g., discharge planning (Currie 2002). But regardless of settings, a standard set of content to communicate would improve the efficiency and effectiveness of shift change (Sexton et al. 2004). Thus a computerized care planning system that can automatically generate a predefined set of information necessary for shift change from the hospital information system appears to be a possible candidate (Cheah et al. 2005).

2.2.4 Communication Failure

Many documented adverse events took place in the medical setting resulted from or contributed by miscommunication between the incoming and the outgoing nurses during shift change, similar to other high-reliability domains (Patterson 2005, Wears et al. 2003). For example, an investigation into the extreme case of the amputation of a patient's wrong leg revealed that the outgoing nurse forgot to tell the incoming nurse during shift change about a clerical error that the incorrect leg to be amputated was put in the surgery schedule. In fact, communication failure is the leading cause of adverse events in hospitals in the United States, in many of which communication during shift change played a contributing role (Strople and Ottani 2006).

Common causes for communication failures found in medical settings include missing information, lack of mental model of the operation, insufficient time for shift change, interruptions during shift change, and handover given by an 'unnamed' nurse. The first three causes were also found to contribute to many communication failures in other high-reliability settings whereas the remaining two appeared to be specific to the medical setting. Understanding these causes is vital to the development of guidelines or technological solutions for improving the effectiveness of shift change.

Missing information may lead to inappropriate patient care and also possibly serious consequences (Alvarado et al. 2006, Currie 2002). To prevent missing information, a checklist of information to communicate during shift change could be an option but this requires a pre-defined set of information necessary for shift change. However, this may not be possible as unexpected information often arises in the dynamic medical settings. Thus, a mechanism that allows nurses to easily and immediately record newly emerging information at points of production could help reduce the occurrence of missing information to be communicated to the next shift.

Lack of mental model of the ward operation at the time of the transition could impede effective shift change (Perry 2004, Wilson et al. 2005). Mediating artefacts that can offer an overview of the operation could be useful.

Insufficient time for shift change may rush nurses through the handover process which easily lead to information being missed or misinterpreted (Meiβner et al. 2007). This unfortunately is prevalent as the cost-benefit trade-off in the budget-tight hospital settings. A solution that allows clinicians to more efficiently document emerging medical information which can then be more readily available to other clinicians including their incoming colleagues should improve the efficiency of shift change.

Interruptions during shift change may deteriorate the quality of communication and may also lead to errors (Perry 2004, Reason 2000, Reddy and Spence 2008) and job dissatisfaction (Meiβner et al. 2007). Interruptions include questions and requests made by patients, and acute events that must be attended to. The former may be mitigated by conducting shift change in a location away from patients and their family, but patient documentation may not be readily available there. However, clinicians must attend to the latter kind of interruptions promptly as patient care is their primary objective.

Handover given by someone other than the named nurse can easily lead to information being missed (Allen 2004, Currie 2002). This typically occurs at team conference when a proxy who first gathered information from other team colleagues gives the report. This practice is likely also to have resulted from the cost-benefit consideration (see Section 2.3.2). In fact, the 'Named Nurse' practice has been highly recommended for improving the accuracy and consistency of information communicated during shift change (Currie 2002).

2.2.5 Quality of Shift Change

"The quality of care is a remarkably difficult notion to define" and how it is defined will have "profound influence on the approaches and methods one employs in the assessment" (Donabedian 1966). Shift change is a time-consuming activity, reportedly requires between 10 and 61 minutes (Lamond 2000, Sexton et al. 2004). Nursing shift change was estimated to cost US$610K per year (based on the 2003 mean salary of an RN) in a 10-ward hospital (Strople and Ottani 2006) whereas another estimate accounted for $1.5 million per year (Hewitt 1997). Therefore, many healthcare organizations measure the quality of shift change in terms of their cost-effectiveness, in dollar measurements (Baldwin and McGinnis 1994, Currie 2002, Strople and Ottani 2006). However, while efficient shift change could allow nurses to spend more time on direct patient care, it is imperative to warrant that the patients are receiving the correct care illuminated during shift change. Otherwise, such time savings in shift change would be detrimental rather than beneficial as a result (Riegel 1985).

The effectiveness of shift change is crucial for improving patient care. Yet there had been relatively few studies on actual shift change practices in the medical field and so little insight into how its effectiveness can be measured and enhanced is available (Wilson et al. 2005). Studying the effectiveness of shift change is challenging. For example, the problem of missing or inaccurate information was usually only recognized after some adverse events occurred (Patterson 2005) and attempts to standardize or formalize shift change process as a means to improve its quality might not lead to the desired outcome (Keenan et al. 2006). For instance, an attempt to formalize nursing shift change with the goal to reduce redundancy actually shifted the redundancy to a different time and space (Munkvold et al. 2006a). In contrast, the dynamic and fluid nature of shift change, along with evidence of positive aspects inherent in the activity such as the rescue and recover function, suggests that using heuristics to guide and enhance shift change process is likely a better approach to improve safety (Perry 2004). The strategies depicted in Table 2.1 would therefore be useful. For example, the first 21 strategies, as identified from Patterson et al.'s (2004) study, had been used to evaluate nursing shift change in four hospital wards and areas for improvement were successfully identified (Patterson 2005).

2.2.6 Technological Support

Although shift change has been well-recognized for its significance in achieving continuity and safety of patient care, previous effort mostly focused on the handover meeting and paid little attention to other activities that are also integral to shift change. In turn, there has been little effort to examine how these activities may be supported by technologies.

Based on a thorough review of existing methodologies for conducting shift change, Baldwin and McGinnis (Baldwin and McGinnis 1994) proposed a computer generated shift reporting system which was in fact a paper form pre-printed with patients' demographics and a list of information headings that needed to be communicated to the following shift. The reports were designed for 24-hour use with color-coded annotation for each shift, and to replace verbal reporting previously practised. Outgoing nurses then wrote down information including abnormal findings and results in the spaces provided.

Therefore, these computer-generated shift reports were similar to written reports except that static information such as patient demographics and medical histories were pre-printed and shift reports of the day were available on the same form. This was reported to result in more time savings and improved communication of pertinent patient data.

Based on standardized nursing terminologies (NANDA, NIC, and NOC), HANDS (Hands-on Automated Nursing Data System) is a software application designed to support the development of care plans (Keenan et al. 2002, Keenan et al. 2006). Nurses were also expected to use this tool to guide their communication at shift handovers. With the built-in nursing care resources, nurses can use selection menus, instead of looking up paper references, to devise care plans for *interventions* and *outcomes* based on patients' clinical *problems* (Figure 2.3). Nurses generally found it useful for developing patients' care plan. However they did not use it for shift change (Keenan 2007). Instead, they still relied on their paper notes for shift reporting. To enforce compliance and adoption, the use of HANDS has become mandatory during shift change. A similar computerized charting system deployed in an Asian hospital ward was also found to facilitate the development of care plans. Yet, it was criticized for ridding nurses of their cognitive thinking activity (Lee 2006). This is likely because the mouse-and-keyboard interaction did not support their 'writing-as-thinking' process (see also Section 2.2.6). These technologies were designed to automate the existing system by replacing the paper references by digital resources. However, the interaction afforded by these technologies did not support current work practices as described. As such, using these computerized systems entailed substantial changes to existing work practices, resulting in resistance or resentment (Hartswood et al. 2003). This again shows the importance of *a priori* thorough understanding of the practices in which the systems are to function so that useful properties in the existing system will be recognized and sustained in the new system (Berg and Goorman 1999, Hutchins 2000, Juhlin and Weilenmann 2001).

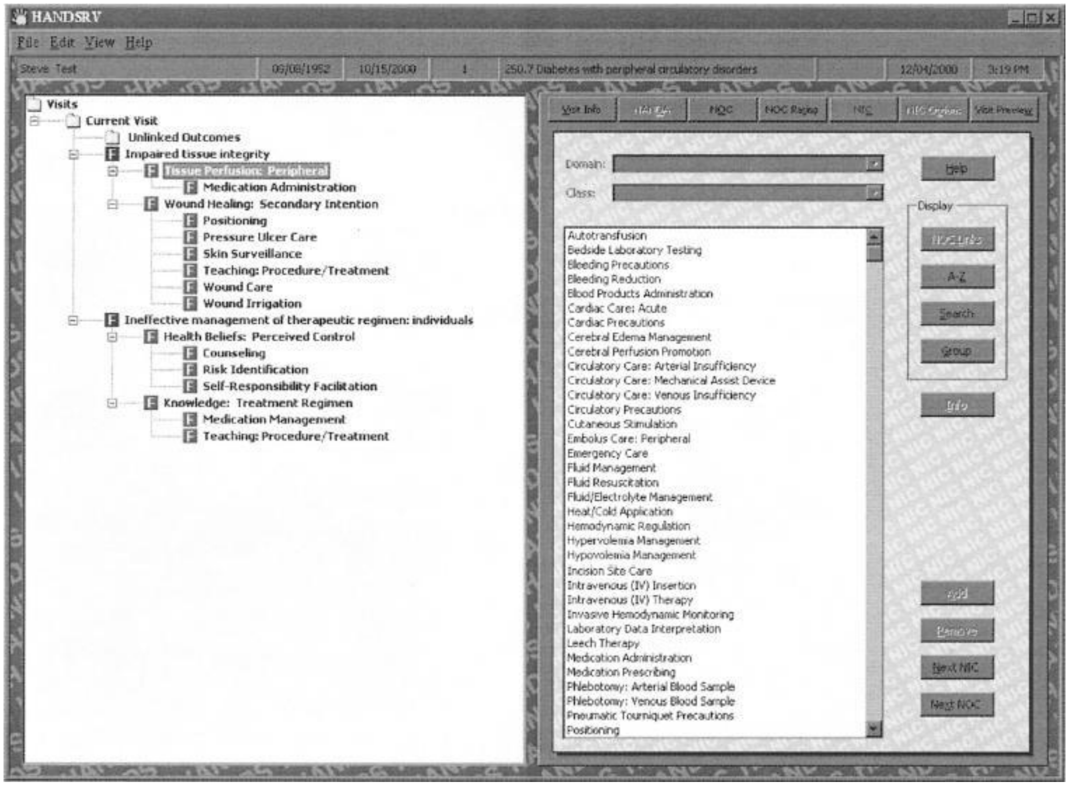


Figure 2.3 HANDS tool Nursing Interventions Classification for generating nursing care plan (Keenan et al. 2002, pp. 97)

2.3 Information Flow in Hospital Wards

A hospital is a vast socio-technical system consisting of many intensive communication networks (Bossen 2002) that include people, equipment, information technologies, routines, and regulations (Wilson et al. 2007). It is also characterized by its information-rich, dynamic, time-pressured, mobile and round-the-clock operations. Clinicians often have to spend an immense amount of time in dealing with a huge quantity of information and in coordinating and synchronizing among various information sources (Ancona et al. 2000) which may be “online or offline, written or verbal, broadcast or personal, structured or unstructured” (Paepcke 1996). Besides, the same information may exist in multiple sources to serve different purposes. Therefore, managing the flow of information has been found to constitute a major problem in hospitals (Turner et al. 2005), and communication failure among clinicians has been reported to be one of the most frequent causes of preventable adverse events to patients (Gurses and Xiao 2006, JCAHO 2007). Information flow is the combination of the processes of information handling by which information can be gathered, stored, exchanged, and dispersed. These information processes make use of any type of available media such as verbal, written, and digital that is deemed appropriate for the current purpose.

Patient care requires effective information flow for achieving shared understanding and work coordination between distributed clinicians (Bossen 2002). But patient demands and resource availability change constantly, rapidly, and often unexpectedly so that contingencies are quite typical, despite extensive *a priori* planning and scheduling of activities (Ash et al. 2004, Bardram and Bossen 2005a, Xiao 2005, Xiao et al. 2003). In order to cope with the dynamic and complex work environment, various *mechanisms of interaction,* such as plans and standard operating procedures, are widely adopted to facilitate coordination in healthcare (Bossen 2002, Suchman 1987, Schmidt and Bannon 1992, Winthereik and Vikkelso 2005). Situated actions or workarounds are also often developed to deal with contingencies and unanticipated events so that patient care can be continued accordingly (Ash et al. 2004, Balka and Kahnamoui 2004, Kobayashi et al. 2005, Star and Strauss 1999).

The following subsections describe characteristics of hospital work that impact the information flow: information-rich work environment (Section 2.2.1), multidisciplinary collaboration (Section 2.2.2), distributed coordination (Section 2.2.3), coordinating artefacts to support information flow (Section 2.2.4), breakdown of information flow (Section 2.2.5), and technological support for achieving effective information flow (Section 2.2.6).

2.3.1 Information Work

A hospital is an information-rich environment in which work is accomplished through cooperation among clinicians possessing different expertise. For example, studies have shown that 50% of information within medical settings came from colleagues, 26% from personal notes, 12% from laboratory results, and the remaining from various sources (Coiera and Tombs 1998, Covell et al. 1985). Thus, people play a significant role in building the information repository and the “web of conversations” constitutes the biggest information system in health care settings (Coiera 2000). Traditionally in medical settings, information was mainly communicated via a variety of media such as verbal, paper, and display medium (Bardram 2000, Cabitza et al. 2005, Kovalainen et al. 1998, Luff et al. 1992, Xiao et al. 2001). But advances in information technology have resulted in an increasing adoption of electronic health records, replacing paper-based records, to provide remote access to clinical information (Hatcher and Heetebry 2004).

While carrying out the work required of a specific position, clinicians constantly gather newly emerging information from an array of information sources, such as by assessing or re-interpreting a patient’s illness trajectory, by evaluating his/her lab reports (either paper or digital), or by consulting another clinician, to dynamically shape treatment and/or care plans to best suit a patient’s current condition (Berg and Goorman 1999, Reddy and Dourish 2002). They also need to disseminate the collected knowledge to appropriate information repositories such as a patient chart, ideally instantaneously so that other clinicians can use the information to decide or adjust the patients’ treatment and care schedule accordingly. Different health professionals may employ varying techniques for gathering information (Cicourel 1990). These information-related activities form an integral part of clinicians’ daily work and require a high level of coordination and collaboration among them as well as timely availability of specific information sources (Gurses and Xiao 2006, Reddy et al. 2006). The perceived credibility of information sources also plays an important role in determining the efficacy of acquired information, which will in turn influence the overall information seeking activities (Cicourel 1990, Paepcke 1996, Strauss et al. 1985).

2.3.2 Multidisciplinary Collaboration

Hospitals were much less differentiated decades ago (Strauss et al. 1985). But the increasing specialization of modern medicine entails collaboration of multidisciplinary division of labour when making a diagnosis and deciding on a treatment and care plan for a patient. This is because each specialty carries specific and often unique information relevant to a patient's illness as well as varying work goals (Gardner et al. 2001, Munkvold et al. 2006a, Reddy and Spence 2008). Therefore, healthcare practitioners must work together to seek, synthesize and disseminate information in addition to carrying out routines and standard procedures when collaborating in the dynamic work environment (Bardram and Bossen 2005a, Reddy and Spence 2008, Sonnenwald and Pierce 2000).

Nurses, in particular, are the ones who "weave together the many facets of the [healthcare] service and create order in a fast flowing and turbulent work environment" (Allen 2004) and are the only group of healthcare professionals with the patients 24 hours a day (Munkvold et al. 2006b). They need to integrate information that exists in a variety of patient records into a "working document" for carrying out their daily work routines. They also need to develop relations across units and departmental lines to a wide range of services such as physicians, laboratories, pharmacy, and even kitchen (Wagner 1993). Thus they carry important information such as the outcome of a particular treatment or patients' responses to a new medicine that the primary care physician needs to know for evaluating the patients' progress (Reddy and Spence 2008).

In addition, medical work is generally ill-defined as compared to other domains making coordination and communication in healthcare more challenging (Reddy and Dourish 2002, Strauss et al. 1985). It requires multidisciplinary effort to negotiate and interpret emerging information throughout the course of a patient's illness trajectory (Ash et al. 2004, Berg and Goorman 1999, Kane and Luz 2006, Reddy and Dourish 2002, Symon et al. 1996). The fragmented nature of healthcare into many finely-specialized disciplines also results in more hand-offs between clinicians of different disciplines. Thus, while the division into specialized disciplines allows clinicians to utilize specific expertise to contribute to patient care, the need to maintain awareness and coordination among multidisciplinary clinicians to achieve medical work becomes more critical for patient safety and healthcare efficiency (Xiao 2005, Winthereik and Vikkelso 2005).

2.3.3 Distributed Nature

Health care in hospitals is a team effort distributed across time and location. The distributed nature of hospital settings makes the coordination necessary for collaborative work complex and difficult. As opposed to other high reliability settings such as the space shuttle mission control where controllers work at their position console only, clinicians often have to locally move around to connect with their collaborators, to maintain awareness of each other, to access information inscribed in distributed coordinating artefacts, to secure needed resources, and to execute specific actions in order to accomplish work (Bardram and Bossen 2003, Bardram and Bossen 2005a, Bardram and Bossen 2005b, Bellotti and Bly 1996, Bossen 2002, Gonzalez et al. 2005, Luff and Heath 1998, Xiao 2005). To do this, clinicians must constantly strive to achieve the right configuration of people, resources, and knowledge for collaborative work (Bardram and Bossen 2003, Bardram and Bossen 2005b). Thus schedules and rhythms of people’s work practices could help others to better estimate an appropriate time and place to move into communication and collaboration (Reddy and Dourish 2002, Zerubavel 1979).

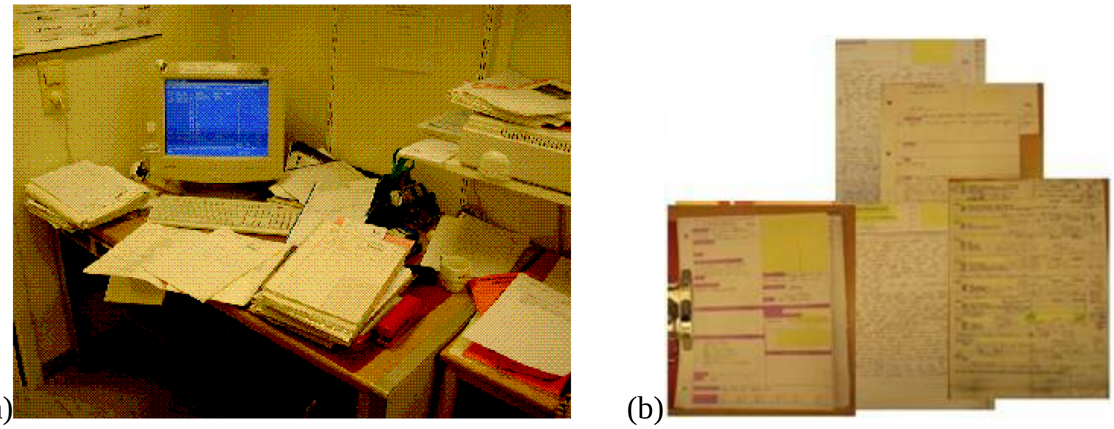
Medical work is also characterized by shift work in order to provide continuous patient care. Although shift change provides the opportunity for communicating accurate and reliable information across shifts, the varying shift cycles that healthcare professionals work increase the complexity of information flow among multidisciplinary clinicians. Thus, a variety of artefacts are used to facilitate information flow among spatially and/or temporally distributed clinicians. The general trend is to shift from paper documents to electronic health records (EHR) to allow remote information sharing.

2.3.4 Coordinating Artefacts

Face-to-face communication is well-recognized for its effectiveness in establishing a shared understanding of information and facilitating collaborative work (Bellotti and Bly 1996, Kraut et al. 1988, Schmidt and Bannon 1992, Whittaker et al. 1994). However, the distributed nature of hospital work often curtails the opportunities for face-to-face communication. Instead, a wide range of artefacts are used to mediate the collaborative work (Bardram and Bossen 2005a, Hutchins 2000, Xiao 2005, Zhou et al. 2009) and to help leverage clinicians' perceptual capabilities (Xiao et al. 2001). Tangible artefacts, with their perceived ease-of-use and their physical presence, were often preferred to be used as a valuable visual reminder in the complex and dynamic healthcare environment (Symon et al. 1996, Xiao 2005). Among them, large displays and paper artefacts are most widely used to coordinate work in hospitals.

Large displays such as whiteboards and bulletin boards are useful for broadcasting information, especially asynchronously, to a large audience from a distance. These displays are also effective for synchronous joint discussion and negotiation (Gonzalez et al. 2005, Wilson et al. 2006, Xiao 2005, Xiao and Seagull 2006, Xiao et al. 2007) and keeping an awareness and coordination of ongoing activities, as shown in

Figure 2.4 Large display for joint collaborative use (Xiao et al. 2005, pp. 30)



(a) (b)

Figure 2.5 (a) Paper use is pervasive in hospitals (Ellingsen et al. 2003, pp. 79) (b) Formal and informal paper documents used by nurses (adapted from Mundvold et al. 2006, pp. 63)

Figure 2.4 (Bardram 2000, Bardram and Bossen 2005a, Reddy and Dourish 2002, Xiao 2005).

Paper-based records offer unique, multiple affordances for viewing, reviewing, annotating and altering data (Heath and Luff 1996, Sellen and Harper 2002). They support non-intrusive note-taking (Harper et al. 1997) and can easily interweave with ongoing conversation which is important for carrying out 'sentiment work' and 'comfort work' (Strauss et al. 1985). They also provide the 'elbow room' needed for initial, exploratory and provisional information, especially when information was tentatively scribbled in pencil, in the course of decision-making such as when making a difficult diagnosis (Fitzpatrick 2004, Hardstone et al. 2004). Therefore, paper documents are pervasive in many workplaces including hospitals (Figure 2.5a)

Other *exogenous* artefacts that are developed externally and then introduced to workplace (Jones and Nemeth 2005) also include mobile technological devices to allow clinicians to access electronic health records at points of care. However, they mostly failed to support clinicians' work practices due to their structured and constrained interfaces that are cumbersome to navigate, and indirect forms of input via mouse and keyboards (Hardstone et al. 2004, Harper et al. 1997). As such, *endogenous* paper artefacts that clinicians create to support their work were vital to accomplishing medical work (Figure 2.5b), despite being under-recognized (Bardram and Bossen 2005a, Fitzpatrick 2004, Hardey et al. 2000). Such endogenous paper artefacts include those that were created for collaborative use, e.g., the Shift Sheet (Zhou et al. 2009), and those that were created for personal use only, such as nurses' "scraps" (Hardey et al. 2000). The Shift Sheet was created for joint use by nurses to cumulatively store a patient's overall information including social issues and emotional needs during her hospitalization in a busy hospital ward and was also served as an important information source at shift change. On the other hand, personal artefacts often allow individual clinicians to flexibly customize information that served as memory triggers to help them plan, manage, and coordinate their work (Bardram and Bossen 2005a, Fitzpatrick 2004). They were then carried around, referred to, actively annotated, and updated throughout the shift work for achieving smooth work flow (Bardram and Bossen 2005a, Fitzpatrick 2004, Paepcke 1996).

2.3.5 Information Flow Breakdown

Failure to achieve the right configuration of people, knowledge and resources could result in an interrupted workflow such as cancellation of patient appointments, wasting of scheduled timeslots, and delay of treatment (Bardram and Bossen 2005b). In fact, some failures may also lead to serious healthcare consequences and costs which may extend far beyond the repeating of the individual scan or patient consultation (Lederman and Morrison 2002).

Communication failure among clinicians, in particular missing information, has been found to be a frequent contributing factor in many preventable adverse events to patients (Gurses and Xiao 2006, JCSHO 2007, Weingart et al. 2000). The complexity and ill-defined nature of healthcare work makes it error-prone which, unfortunately, may be latent or hidden within the complex work (Ash et al. 2004, Strauss et al. 1985). Therefore, many hospitals were vigilant in taking a proactive approach hoping to identify latent problems before an adverse event occurs (Reason 2000). They also purposely built in data redundancy in collaborative work for safeguarding the accuracy and consistency of information to be communicated among clinicians (Cabitza et al. 2005, Ellingsen and Monterio 2003, Helleso and Ruland 2001, Hutchins 1994, Munkvold et al. 2006a, Munkvold et al. 2006b). To further minimize communication breakdown, attempts were also made to standardize clinical information using information technologies (Ash et al. 2004, Bardram 1997, Bardram et al. 2006, Munkvold et al. 2006b, Winthereik and Vikkelso 2005).

Since the release of the “To Err is Human” report in 2000 (Kohn et al. 2000), clinical incident reporting systems have been extensively adopted to retrospectively keep track of near misses and real adverse events that point to vulnerabilities in the healthcare system (Galliers et al. 2004, Miller et al. 2006). The problem with this reporting system is that errors in healthcare were so frequent and the amount of data collected through these tools was so tremendous that an “average patient safety officer would have a full plate for the next five years without a single new report” (Miller et al. 2006).

A more proactive method for determining information flow breakdown in clinical environments was also developed (Galliers et al. 2004). This method involves *in situ* data collection for specific activities which will then be analysed in detail based on scenarios. Points of vulnerability are thus identified for remedy. This method was reported to help identify latent problems that could potentially lead to adverse events.

2.3.6 Technological Support for Distributed Information Flow

This section highlights several popular information and communication technologies deployed in hospitals, specifically electronic health records, mobile information technologies, and mobile communication technologies.

Electronic Health Records

Paper medical records are increasingly replaced by electronic health records (EHRs) to provide more consistent, integrated, distributed, and timely sharing of up-to-date information and to reduce redundancy of effort for updating patient information (Berg 1999, Ellingsen and Monterio 2001, Harper et al. 1997, Helleso and Ruland 2001, Sellen and Harper 2002, Skov and Haegh 2006). EHRs also have the ability to offer diverse representations of the same information (Hutchins 2000, Reddy et al. 2001) and secondary utilization of healthcare data (Berg and Goorman 1999) to meet varying needs of multidisciplinary healthcare professionals for enhancing the quality of healthcare.

Yet, the EHR system has been criticized for not delivering benefits as expected (Ellingsen and Monterio 2001). One main criticism is that EHRs are built upon a hierarchical system approach, thus cumbersome navigation is often required for accessing information and data entry is constrained by structured data fields which were often spread over multiple screens. Thus the time cost of interaction with the information system is considered high. Navigation across screens also easily leads to a loss of mental focus and overview compared to their paper-based predecessors (Ash et al. 2004). Clinicians also reported that many interfaces of and interactions with the EHR system did not match their use context and work practices (Abowd and Mynatt 2000, Ash et al. 2004, Heath and Luff 1996). For example, ‘writing-as-thinking’ is an important process to help clinicians cognitively plan, manage and analyze patient information as they were working on a case (Ash et al. 2004) but EHRs utilize indirect form of interaction using mouse and keyboard which fails to support their cognitive thinking process.

Mobile Information Technologies

As healthcare is moving away from paper-based records to electronic patient information, real-time mobile access to critical data appears to be the logical next step. Therefore, there is an increasing adoption of mobile information technologies in medical settings (Bardram and Bossen 2005b, Bellotti and Bly 1996, Gurses and Xiao 2006, Luff and Heath 1998, Moran et al. 2007, Cisco 2007a). Popular technologies including handhelds and computers-on-wheels, as well as emerging technology that bridges the physical-digital divide will be discussed next.

Table 2.2 Benefits and drawbacks of PDAs used in hospitals

Benefits	Drawbacks
• Integrated PDAs offer real-time remote access to patient information (Gurses and Xiao 2006, Rogoski 2004, Skov and Haegh 2006, Sommers et al. 2001) • Savings in time and effort, e.g., prescription and lab test ordering at points of care (Gardner et al. 2001, Turner et al. 2005) • Error reduction (Lu et al. 2005) • Documentation at points of care (Lu et al. 2005, Turner et al. 2005) • Positive clinical impact, e.g., more time for patients, better decision support (Lu et al. 2005) • Education and research support (Gardner et al. 2001, Lu et al. 2005)	• Issues on network security, connectivity and speed of wireless transmission (Brewster and Dunlop 2000, Lu et al. 2003,Turner et al. 2005) • Slow processors (Brewster and Dunlop 2000) • Limited memory (Lu et al. 2005) • Possible interference with medical equipment (Turner et al. 2005) • Non-integrated with hospital information system offers limited functionality (Lapinsky et al. 2001, Lu et al. 2003) • PDAs not synchronizing with hospital information system may lead to information inconsistency (Hewlett-Packard, accessed 2009) • Small screen, constrained data entry mechanism, perceived fragility (Brewster and Dunlop 2000, Lapinsky et al. 2001, Lu et al. 2003, Hewlett-Packard, accessed 2009) • Short battery life (Lu et al. 2003, Turner et al. 2005) • Non-intuitive graffiti (Lu et al. 2003) • Non-intuitive virtual keyboard (Turner et al. 2005) • Not User-friendly (Lu et al. 2003) • Negative patient perception (Lu et al. 2003)

Personal Digital Assistants (PDAs) are versatile and relatively inexpensive nowadays. Therefore, PDAs are widely used in hospitals, either purchased by individual clinicians to facilitate their own work or implemented hospital-wide for enhancing collaborative work (Figure 2.6). In either case, PDAs that are not integrated with a hospital information system typically only offer to-do lists and reminders, and access to installed and web-based medical references (Lapinsky et al. 2001, Turner et al. 2005). Yet looking up medical references using a PDA was not found to be more satisfactory and efficient than using printed copies of medical handbooks (Lapinsky et al. 2001).

On the other hand, integrated PDAs that synchronize with hospital information system also offer clinicians ubiquitous, real-time remote access to up-to-the-minute patient information (Gurses and Xiao 2006, Rogoski 2004, Skov and Haegh 2006, Sommers et al. 2001). I compiled Table 2.2 to compare and contrast the benefits and drawbacks of PDA use in medical settings. Despite the perceived benefits of PDAs to allow ubiquitous information access and to support work, their drawbacks may shed light

Figure 2.6 Clinicians graffiti on PDAs (Turner et al. 2005, pp. 214)

on why many clinicians still rely on written notes in paper documents for patient information, and refer to pocket textbooks or references even where resources are available online (Lapinsky et al. 2001).

Tablet PCs combine desirable features of paper, notebook PCs, and PDAs to provide remote access to EHRs while accepting handwriting interaction on a larger screen. For many users, handwriting is quick and intuitive so is preferred over typing at a keyboard or graffiti on a small PDA screen (Gardner et al. 2001, Turner et al. 2005). Tablet PCs can be used as a traditional notebook with full computing functionality; they can also be converted into a slate for writing (Figure 2.7). Handwritings can also be converted to digital texts using a recognition application (Hewlett-Packard 2009, Microsoft 2009).

Figure 2.7 Tablet PC used for educating patients (source: Cisco 2007b)

An integrated Tablet PC allows clinicians to enjoy the benefit of mobile and ubiquitous access to hospital information system and other medical applications similar to using an integrated PDA. The larger screen of Tablet PCs also helps facilitate interaction and viewing although their size and weight make them less portable than PDAs. Besides, they are considerably more expensive.

Computer-On-Wheels (COW) is a computer or a notebook placed on an ergonomically designed trolley running on a wireless network so that they can be wheeled to anywhere, typically within a hospital ward. They were designed to allow clinicians to wirelessly access patient's EHRs at points of care via conventional interaction mechanisms, i.e. mouse and keyboard. The availability of information at points of care reduces clinicians' walking back and forth to stationary desktop computers and/or nursing stations for looking up medical information and references. Clinicians can also enter patient information at the bedside. In addition, COWs were expected to help reduce or replace paper use and to support real-time sharing of newly emerging information with other clinicians (Cisco 2007a).

While EHRs are essential to modern healthcare, most current information devices fail to support work practices as pointed out by the Institute of Medicine of the National Academies that "perhaps the single greatest challenge that has consistently confronted every clinical system developer is to engage clinicians in direct data entry", thus it is important "to make it simple for the practitioners to interact with the record, data entry must be almost as easy as writing" (Institute of Medicine 1997).

Digital Pen and Paper offers familiar interaction while the handwritings can be readily digitized for distributed sharing. Therefore, digital pen and paper technology has the potential to seamlessly integrate paper into the hospital information system and to enhance and integrate with existing work practices (Cohen and McGee 2004, Morán et al. 2007). In most hospitals, traditional single-copy paper-based patient charts are still in use for recording patient's illness trajectory in a designated location, typically the nursing station. An augmented patient chart system was designed and evaluated in a public hospital in Mexico (Zamarripa et al. 2007). It utilized digital paper that required the use of a digital pen to capture information directly to the digital medium which can instantly be shared with other clinicians. Initial results were encouraging in terms of the savings in time and the accuracy of information stored in the database.

Mobile Communication Technology

Quick and frequent communication among clinicians is often required to achieve work coordination and collaboration in the dynamic, time-critical, distributed and multidisciplinary hospital environment. Therefore, mobile technology that provides a low-cost communication medium that dispersed collaborators can use to communicate frequently and spontaneously would be beneficial to support collaboration and coordination, and to reduce unnecessary mobility and effort to look for collaborators in medical work (Bardram and Bossen 2005b, Kraut et al. 1988, Luff and Heath 1998, Morán et al. 2007). As such, the clinicians can spend more time in actual patient care (Head 2007, Gurses and Xiao 2006, Morán et al. 2007).

Paging Systems were traditionally the primary communication channel for connecting with distributed clinicians. Although paging systems are still in use in many hospitals, other communication technologies are increasingly used to offer instantaneous two-way communications.

Figure 2.8 Single-button push to call on Vocera (source: IBM 2008)

Mobile Voice Communication Systems are increasingly deployed in hospitals to enable distributed clinicians to conduct two-way communication directly.

Personal Handy-phones System (PHS) was deployed among doctors and nurses in a hospital in Japan so that they could verbally communicate with each other both inside and outside the hospital (Hanada et al. 2006). This system led to a 35-50% reduction of calls to fixed-line telephones which clinicians had to spatially move in order to communicate. It also helped reduce the searching time for locating other clinicians. The savings in time allowed clinicians more time to spend on actual patient care which has significantly improved medical safety and work efficiency.

Vocera® is gaining popularity in hospital settings. It provides hands-free operation without dialling or typing, coupled with voice recognition technology to allow clinicians to communicate directly with a button-push (Figure 2.8). Vocera implemented in a Canadian hospital was found to significantly improve time-savings in searching for other clinicians and in trips to telephones. 25% less time was spent on key communication activities with the use of Vocera (IBM 2008).

In another Canadian hospital, the implementation of Vocera was partially funded by ‘Violence in the Workplace Committee’ that focused on reducing the risk of workplace accidents, such as violence and assault in the workplace (Archer 2009). The safety feature is activated by pressing the Vocera button twice, which immediately alerts hospital security. The clinician can then communicate with the security on-site. With Vocera, the non-urgent and urgent response times were found to have improved by 95% and 61% respectively.

As each type of technology supports information flow in different ways, an integrated network consisting of heterogeneous technologies could potentially combine all their best features to support work coordination and collaboration in a mobile and pervasive computing hospital environment. As such, a medical-grade network consisting of 40 Vocera hands-free communication badges, 10 computer-on-wheels and 6 Tablet PCs running on 40 wireless networking access points were deployed in the emergency ward of an Australian children's hospital (Cisco 2007a). The networked platform supports electronic medical records, computerized physician order entry, communication system, medication dispensing, and a range of other important functionality. It was reported that the deployment resulted in an improvement in the efficiency, quality and safety of patient care, and patient satisfaction, as well as financial gains of 20 hours of staff time per day in the ward. An extrapolation across all the wards would likely result in savings of more than US$7 million a year (Cisco 2007b).

With the positive outcomes offered by technological intervention, there has been increasing trend to deploy various kinds of "state-of-the-art" technologies in hospital settings. Many also aim to achieve a paperless hospital (e.g., Microsoft 2009). However, while employing technologies to help improve work outcomes, evidences have indicated that attempts to make drastic changes to existing work practices could undermine the adoption and ultimate acceptance of the deployed technological system (Ash et al. 2004, Symon et al. 1996) and "will almost certainly fail to account for all the embedded, intangible safety factors and are likely to result in dangerous, perhaps fatal, situations" (Mackay 1999). Thus, health care information and communication systems should be designed with an in-depth understanding of the social organization of the specific medical setting (Ash et al. 2004, Balka and Kahnamoui 2004, Berg 1999, Grudin 1988, Heath and Luff 1996, Strauss 1987).

2.4 Chapter Summary

This chapter provides the foundation for the knowledge that underpins information flow in the complex and dynamic hospital work settings to be explored further in later chapters. It has shown that while technologies, both software applications and hardware devices, deployed to support information flow offer varying features for facilitating information flow among clinicians, these technologies still do not support many of the important work practices that clinicians use to carry out their work.

There are gaps in this prior work. First, its investigations on shift change in medical settings mainly focused on the verbal handover element of the shift change process. However, it did not consider other activities integral to the *information flow during shift change.* Second, it identified that paper personal artefacts were important for clinicians to carry out their work. However, is not clear how these personal artefacts are used *in the course of delivering patient care* and *what aspects of their usage are important to clinicians* when designing the supporting technologies. Rather, mobile devices, such as PDAs, installed with the same hierarchically-structured information system often appeared to be the natural solution.

To address these gaps, Chapter 3 introduces an observational study specifically designed to acquire a better understanding of the basic dynamics and practices used for information flow during shift change. The study is also designed to reveal the importance of paper artefacts that clinicians rely upon. Chapter 4 will contrast the paper artefacts' roles in nurses' information flow against the affordances and interactions offered by a mobile technology and show how the mobile technology failed to support these important functions that are crucial for patient care delivery.

The current chapter also describes several characteristic aspects of general information flow in hospital settings, which helps to ground the development of the framework presented in Chapter 5. This framework is subsequently used throughout the remaining chapters to assess a new technology and to help generate technology designs.

This dissertation is only one step towards developing technological solutions that have the potential to improve the information flow, e.g., by reducing the occurrence of erratic information flow at shift change and during a work shift. In particular, understanding how to design technologies that also integrates into nurses' existing work practices needs further investigation.

Chapter 3. Information Flow Dynamics and Practices during Shift Change

To complement the research presented in the previous chapter and to address the question of how to design technology that can better support the task of information exchange and fit more seamlessly and less obtrusively into the working environment, this chapter presents an in-depth investigation to examine nurses' information flow, focusing on the specific communication practices that compose the fundamental and important information flow during nurses' daily shift change. In order to provide the best possible healthcare to patients, nurses working in different shifts must work collaboratively to ensure that all patient care tasks are carried out properly. This is also why efficient and accurate flow of information between nurses in consecutive shifts is so important.

Previous studies mostly focused on verbal handovers without describing how the verbal handover fits into the larger picture of information exchange across shifts. Therefore, the purpose of the observational study presented in this chapter was to acquire a better understanding of what and how information flow activities were currently performed during shift change and how these activities relate to the overall information flow during shifts, in order to acquire insights into how technology could be designed to support these activities (Schmidt and Bannon 1992, Strople and Ottani 2006). To restate, this study focused on the basic practices of information flow during nurses' shift change and across the actual shifts, and on how technologies impact the efficiency and effectiveness of the information flow processes.

I employed the concept of common information spaces (CIS) in the analysis to explore how a common understanding of a work situation and its coordination is achieved through a combination of information, its representations and interpretations (Bannon and Bodker 1997, Schmidt and Bannon 1992). For the purpose of the analysis, I regard a personal information space (PIS) as an information space that consists of both artefacts and assigned meaning similar to the CIS but is constructed, interpreted and manipulated by only one person. The PIS described here is not the same as the personal or local information space described by Schmidt and Bannon (1992), which refers to the local mindset within an individual or some common beliefs among a group of people. This CIS/PIS perspective is taken to study the information spaces involved in the information flow as these considerations are expected to help inform the design of technology for supporting and bridging these information spaces.

I will first describe the research site where all the studies presented in this dissertation were conducted and several limitations as bounded by the ethics and by the minimally-intrusive nature of the study. Then in the remainder of this chapter, the methodology of the observational study is presented, followed by general observations on how nurses acquire and dispense information from the study. Next, the information media types and the information artefacts involved, how the information seeking and distribution processes are carried out, and how and what information is transposed from a multitude of information artefacts to personal information artefacts are presented.

3.1 Research Site

I have chosen the Medical Ward of the 21st Century (W21C) in a local urban hospital to be the case study for my research. This ward is a uniquely designed hospital ward with two principal goals: “to create a novel hospital-based physical infrastructure that would provide opportunities for creating health care solutions in the broad spectrum of internal medicine… and to create a novel research environment around this new infrastructure” (Baylis 2005).

The study ward is an acute medical teaching unit. Patients admitted to this ward are often transferred directly from the Intensive Care Unit (ICU). Therefore, the patients generally still require acute care for a vast array of, often multi-system, illnesses. However, the nurse-to-patient ratio ranges from 1:4 to 1:8 depending on work shifts, as opposed to the drastically lower ratio of 1:1 or 1:2 in the ICU. Therefore, nurses working at this ward constantly face high stress and time pressure. Yet, these nurses are recognized for their enthusiasm towards their work and the strong dynamic team environment that they have built in such a high-stress and time-critical hospital ward. In addition, innovative research activities frequently take place on this ward as a test-bed before technologies are deployed in other hospital wards. Therefore, nurses working on the ward are generally open-minded towards technology. The nurses whose images are identifiable in this dissertation have given written consent for their images to be included in the documentation because they feel that they are well represented by this research. However they still did not want specific quotes to be attributable to a given nurse. Thus, pseudonyms are used in the quote extracts and illustrations in this dissertation.

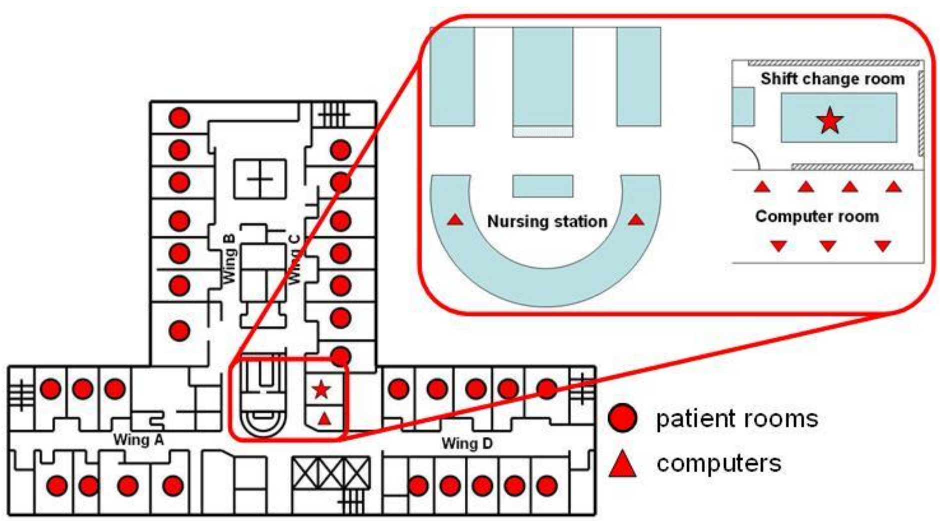


Figure 3.1 (bottom left) Floor plan of the W21C, (top right) Layout showing the nursing station, shift change room and computer room.

Figure 3.1 shows the layout of the ward. The ward is configured with a star design having a centrally located nursing station (see also Figure 3.2a) and four radiating ward wings of patient rooms (see also Figure 3.2b). Its layout makes it convenient to access information at the central information hub but makes it hard for nurses working in different wings to communicate and to maintain awareness. Two wired desktop computers are available in each ward wing; nurses sit on high backless stools when working at these computers (Figure 3.3a). The computer room beside the nursing station is placed with seven wired desktop computers, equipped with comfortable padded chairs (Figure 3.3b).

(a) (b)


Figure 3.2 (a) Nursing station (b) Outgoing nurse giving verbal shift report to her incoming colleague in a ward wing

(a) (b)


Figure 3.3 (a) Working at desktop computer in a ward wing (b) Computer room with desktop computers (also known "physicians' area")

3.2 Limitations

While my goal was to acquire a thorough understanding of the basic information flow practices during nurses' shift change presented in this chapter and the impact of technology deployments on nurses' communication and information flow presented in Chapters 4 and 6, the studies were constrained by ethical limitations. In particular, the ethics protocol for these studies did not allow researchers to enter patient rooms and to use recording devices (audio and video-recorders). This is because there were ethical concerns about accidentally capturing information pertinent to patients who did not or could not consent to participating in the studies. Meanwhile, in order to remain minimally-intrusive during the studies, I sometimes had to keep a distance from the participants during observations, making it difficult to capture the conversational contents, e.g., people's actual talk during verbal handovers between the nurses and charge reporting between a nurse and the charge nurse. To compensate, I always followed up with informal interviews, whenever possible, to gather the missing information and to clarify misunderstandings. Similarly, I followed up by interviewing the nurses for the information flow activities that they performed inside patient rooms.

3.3 Methodology

I employed a naturalistic approach to perform an observational field study in the research site to acquire a better understanding of the current practices of information flow during nurses' shift change. For clarity, I use "ancillary professionals" to stand for a variety of allied health professional groups such as physiotherapists, respiratory therapists, occupational therapists, speech therapists, and social workers.

3.3.1 Participants

Participants in this study were 2 patient care managers, 37 registered nurses and 3 undergraduate nursing students, all of whom were employees of the ward. I use the term "nurses" for registered nurses and student nurses hereafter for simplicity. Five of the nurses were male and the patient care managers and students were all female.

3.3.2 Setting

While some shift change activities such as face-to-face communication between nurses of consecutive shifts may occur inside patient rooms or along corridors of the four wings in the ward (Figures 3.2b and 3.3a), most of the shift change activities take place in and around the nursing station (Figure 3.2a), the shift change room (Figure 3.4a) and the computer room (Figure 3.3b). It should also be noted that although the computer room is not officially designated for use by clinicians of any specific discipline, nurses generally can only use the computer room during night/day (~7am) and evening/night (~11pm) shift changes because physicians always occupy this space during day/evening shift change (~3pm) as a result of the organizational norm. Thus the computer room is commonly referred as the "physicians' area".

3.3.3 Procedure

To obtain a better understanding of the current information flow practices, a minimally-intrusive observational study of information flow during shift change in the ward was conducted, combined with the shadowing of nurses during shift change (without entering

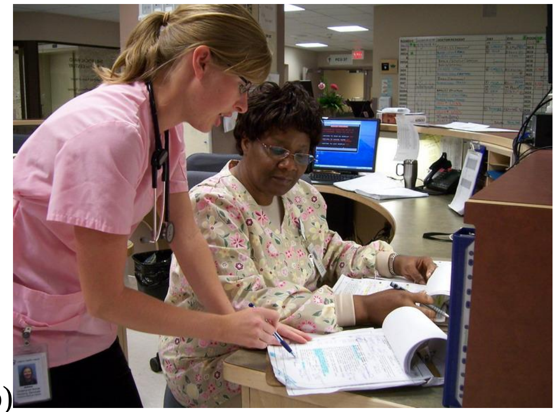
(a)  (b) 

Figure 3.4 (a) Incoming nurses preparing their personal notes for their shift inside the shift change room (patient identities are masked for ethical reason) (b) Outgoing nurse reporting to charge nurse at nursing station patient rooms) and informal interviews. Twenty-five observation sessions were conducted during all nursing shifts, i.e., day/evening, evening/night and night/day shift changes. Observational data were recorded with pen and paper. In addition to the observational notes, copies of the incoming and outgoing nurses' paper artefacts, specifically *personal notes* and/or *patient care summaries*, which were created and/or annotated at the beginning of their shift and used to assist their work during their shift, were collected. Interviews were also conducted with the nurses, whenever possible, to follow up with descriptions and explanations of the personal notes and/or the patient care summaries and how they used them during their shift.

Observations were mainly conducted at/during the following locations and activities:

- Inside the shift change room (Figure 3.4a): I observed outgoing nurses updating the large whiteboards and incoming nurses preparing for their shift.
- In and around the nurses' station (Figures 3.2a, 3.4b, and 3.5a): I observed outgoing nurses giving verbal shift report to their incoming colleagues and outgoing nurses performing verbal reporting to the charge nurse.
- In the computer room (Figure 3.3b): I observed nurses performing digital charting of patient information.
- Shadowing nurses: without going into patient rooms, I shadowed incoming nurses to acquire a better picture of how they prepare for their shift by accessing a diversity of spatially distributed information artefacts.
- Charge nurse handover (Figure 3.5b): I observed how an outgoing charge nurse reports to the incoming charge nurse.

Inside the Shift Change Room

Observations were made inside the shift change room, which is access-controlled for only authorized personnel such as doctors and nurses, to look for what actions participants undertook to prepare for their shift. Specifically, incoming nurses were observed to read and extract information from the patient care summary and shift reports posted on the whiteboards to prepare personal notes and/or an annotated patient care summary for their shift work. I also observed outgoing nurses updating whiteboards inside the shift change room and what physical artefacts they used during the posting. Verbal reporting was sometimes observed as well.

Charge reporting

Outgoing nurses were observed when reporting to the charge nurse. I wanted to see if and what physical artefacts were used when they were making the verbal reports. Since I tried to keep the observation minimally intrusive, it was often difficult to capture meaningful and complete report contents. However, I tried to follow up with short interviews with the outgoing nurses and sometimes the charge nurse as to what types of information were being reported and how charge nurses used their own copy of the patient list which is specifically used by charge nurses for three shifts in a day.

(a) (b)

Figure 3.5 (a) Outgoing nurse verbally reporting to incoming nurse at the nursing station (b) Charge-to-charge reporting with the attendance of incoming unit clerk

Computer Charting

Outgoing nurses were observed when charting patient information at computer workstations. The goal was to find out if and what intermediary artefacts were used and the types of information being charted, and to approximate the time taken for the charting process.

Shadowing Incoming Nurses

Incoming nurses were observed when preparing for their shift to find out the information flow routines and the order in which nurses undertook these routines during shift change. I followed up by interviewing the nurses for the information flow activities they performed inside patient rooms.

Charge Nurse Handover

The meetings between the incoming and outgoing charge nurses were observed. The goal was to get a better understanding of what kind of information was communicated and what intermediary artefacts were used for the information flow. During night/day and day/evening shift changes, the incoming unit clerk would also be present to listen to the reports so that the unit clerk also acquired a picture of the ward operation.

In addition to these observations and informal interviews, copies (photocopies, snapshots, or originals) of the participants' personal notes and/or their annotated patient care summaries were also obtained, both at the beginning and at the end of their shift, for the analysis.

3.3.4 Analysis Method

Analysis took place in two distinct activities. First, the field data was analyzed to identify activities during shift change and each activity was broken down into constituent actions. Second, the collected information artefacts, i.e. personal notes and annotated patient care summaries, were analyzed to identify categories of information that were placed in these personal artefacts.

3.3.4.1 Identifying activities and constituent actions during shift change

Open coding (Strauss and Corbin 1990) was used to analyze the field data to identify activities and their constituent actions during shift change. An initial set of codes was first established from an initial understanding of the field data, i.e. after the data was collected but before it was rigorously analyzed. I then went through all field notes, and assigned these codes to the observed events. Each event could be assigned with multiple codes and the codes were used to mark any reoccurrences of similar events. New codes would be created if existing codes did not fit the event. For example, [VREPORT] was present in the initial list of codes to represent "outgoing nurse giving a verbal report to an incoming nurse". However, this code did not fully describe events where the verbal reporting involved active interaction between the outgoing and the incoming nurses through questions and answers. Thus, a new code [Q&A] was created to augment the description of the event. Similarly, a new code [RNOTES] was created to describe a constituent action when the nurse referred to his/her own notes during the verbal reporting. The codes generated were then examined and similar ones were grouped into themes. For example, [RCHARGE] – read charge board, [RCHART] – read patient chart, and [RPCS] – read patient care summaries were all for seeking information, so a new code [INFO ASSEMBLY] was assigned. A list of codes for the study can be found in Appendix B.1 where the column "Codes I" are the final low-level codes and "Codes II" are the final high-level themes.

3.3.4.2 Identifying information categories on personal information artefacts

Open coding technique was used to analyze the personal notes and the annotated patient care summaries that were collected during the study. The goal was to identify the categories of information that were extracted from various information media (e.g., from paper patient charts and verbal reports) and how the information helped them carry out the tasks during their shift. For example, some information was intended for use as reminders whereas some was used for patient care scheduling purposes. Appendix B.2 shows a tabulation of the information content types that were found from the collected personal notes, as well as their spatial organization and visual augmentations. A category of codes were also generated for the information function types such as “demographics”, “to-do”, and “scheduling”. The information content and function classifications were then informally presented to and verified by several participant nurses who agreed that they correctly represent the information required to carry out their tasks and their intended use.

The open coding analysis method has been widely used and accepted in social sciences research. Therefore, I will focus on the results instead of the low level details of the raw data and its analysis in the remainder of this chapter.

3.4 Results

I first present some general observations. I then describe the types of information media that nurses access during shift change, the information content and function types that were identified from the personal artefacts collected during the study, the types of information spaces (CISs and PISs) that I use to describe and analyze the observations, and the types of information processes that were identified in the study.

3.4.1 General Observations

Incoming nurses were observed to move around the ward to access, gather, interpret, negotiate and manipulate information placed in a multitude of information artefacts constructed by nurses in previous shifts and professionals in other disciplines such as physicians and ancillary professionals. They created personal notes with the information they gathered, assigned meaning, negotiated and manoeuvred from the information artefacts to guide, remind, prompt, schedule and adapt for use in their shift work. Finally at the end of a work shift, they became the outgoing nurses, who then contextualized, organized, and transposed information from their personal notes back to the information artefacts from which they had foraged for information at the beginning of their work shift.

Observations were conducted on a total of 40 incoming nurses (37 nurses and 3 student nurses) inside the shift change room to investigate what and how they prepared for their shift. All the nurses observed prepared some form of personal notes, either on a separate sheet of paper and/or as annotations on the printed patient care summary. Specifically, 75% wrote down notes on a separate note-sheet and 25% used the annotated patient care summary as their personal notes. For those using a separate note-sheet, all assigned specific locations for specific types of information (i.e. designated spatial arrangement), e.g., vital signs were always placed in the top right corner, 40% highlighted information they deemed important or needed attention during their shift (e.g., underlined, circled or marked with a highlighter pen), and 10% color-coded important information. I also found that the majority (83%) wrote down the notes from the previous shift (i.e. shift reports), either from the large whiteboard inside the shift change room or from the verbal report by the outgoing nurse, on the same note-sheet. 10% wrote that as annotations on the patient care summary and the remaining 7% relied on their memory.

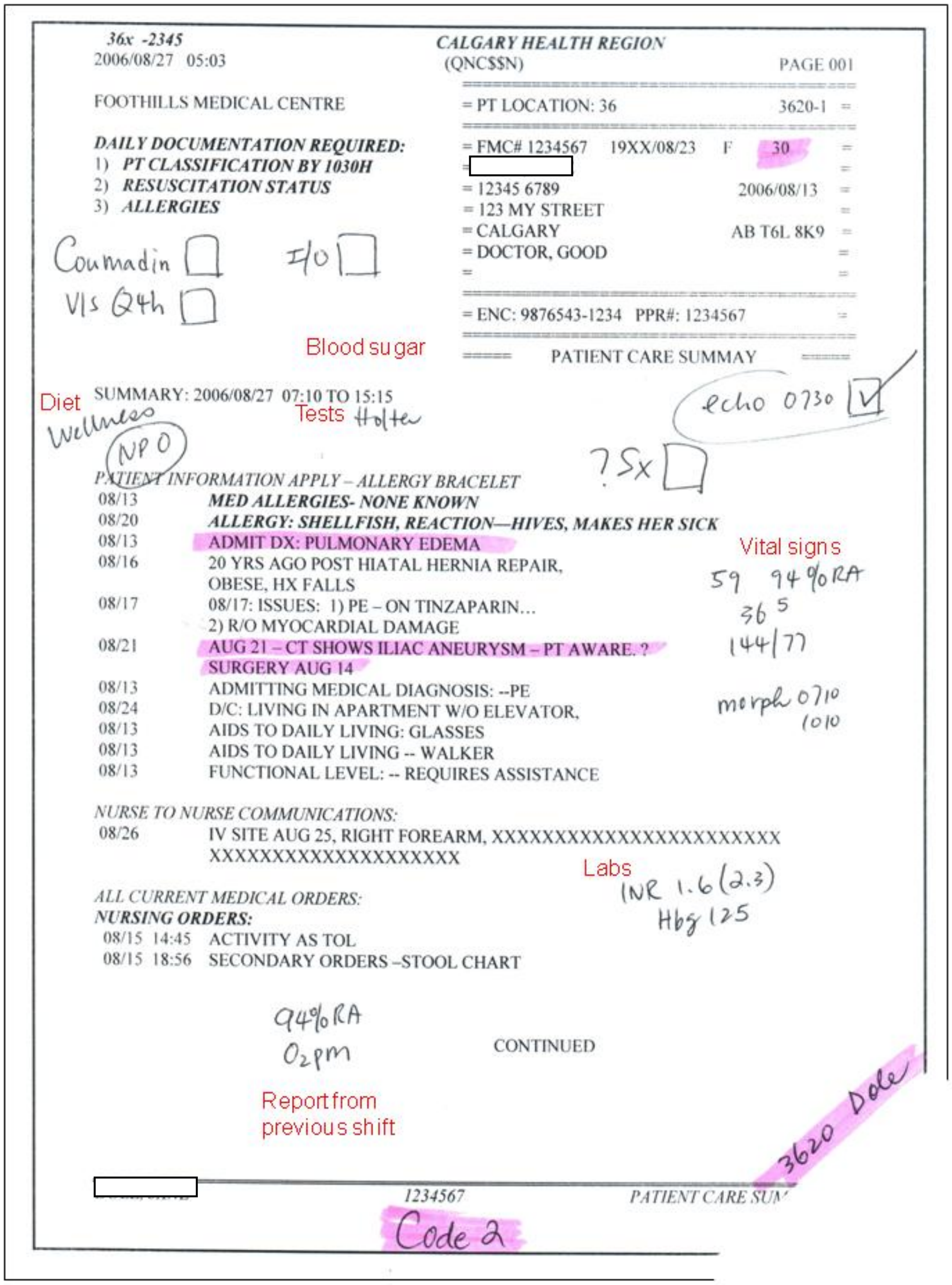
While shift change should be completed officially within 15 minutes (e.g., evening shift 3:00-3:15pm), the observations indicated that it took much longer. To illustrate, several incoming nurses had been inside the shift change room preparing for their shift since 2:30pm, and suddenly a nurse commented, “Why is Helen not here yet?” The researcher looked at her watch and it was 2:45pm, so she asked, “Doesn’t shift change start at 3 till 3:15 (pm)?” All the nurses there chuckled and one said, “yeah, not if you want to be prepared for your work!” All others agreed.

Incoming nurses were observed to require typically between 30 to 45 minutes, depending on if they are assigned new patients and if there are complicated cases in their assignments, to complete assembling the information that they would need during shift change.

Figure 3.6 Incoming nurses engaging in social interaction while preparing for their shift inside the shift change room during shift change

The star configuration of the ward layout spatially separates nurses during their shifts. The spatial distribution often makes them unaware of what was going on in other wings. Therefore, most nurses rely on the opportunity to get together inside the shift change room for social interaction during shift changes (Figure 3.6).

There are several important categories under which I will discuss the observations. These are the types of information media, information contents and functions, information spaces, and information processes through which the nurses interact with these media, content and spaces. While I feel that it is the processes that are of the most interest in the observations, I will discus them last since these processes use the media, content and spaces.



36x -2345
2006/08/27 05:03

CALGARY HEALTH REGION
(QNC$SN) PAGE 001

FOOTHILLS MEDICAL CENTRE
= PT LOCATION: 36 3620-1 =

DAILY DOCUMENTATION REQUIRED:
1) ***PT CLASSIFICATION BY 1030H***
2) ***RESUSCITATION STATUS***
3) ***ALLERGIES***

= FMC# 1234567 19XX/08/23 F 30 =
=
= 12345 6789 2006/08/13 =
= 123 MY STREET =
= CALGARY AB T6L 8K9 =
= DOCTOR, GOOD =
=

= ENC: 9876543-1234 PPR#: 1234567 =

===== PATIENT CARE SUMMAY =====

SUMMARY: 2006/08/27 07:10 TO 15:15

PATIENT INFORMATION APPLY – ALLERGY BRACELET

08/13	***MED ALLERGIES- NONE KNOWN***
08/20	***ALLERGY: SHELLFISH, REACTION—HIVES, MAKES HER SICK***
08/13	ADMIT DX: PULMONARY EDEMA
08/16	20 YRS AGO POST HIATAL HERNIA REPAIR, OBESE, HX FALLS
08/17	08/17: ISSUES: 1) PE – ON TINZAPARIN… 2) R/O MYOCARDIAL DAMAGE
08/21	AUG 21 – CT SHOWS ILIAC ANEURYSM – PT AWARE. ? SURGERY AUG 14
08/13	ADMITTING MEDICAL DIAGNOSIS: --PE
08/24	D/C: LIVING IN APARTMENT W/O ELEVATOR,
08/13	AIDS TO DAILY LIVING: GLASSES
08/13	AIDS TO DAILY LIVING -- WALKER
08/13	FUNCTIONAL LEVEL: -- REQUIRES ASSISTANCE

NURSE TO NURSE COMMUNICATIONS:
08/26 IV SITE AUG 25, RIGHT FOREARM, XXXXXXXXXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXXXXXX

ALL CURRENT MEDICAL ORDERS:
NURSING ORDERS:
08/15 14:45 ACTIVITY AS TOL
08/15 18:56 SECONDARY ORDERS –STOOL CHART

CONTINUED

1234567 *PATIENT CARE SUM*

Figure 3.7 The first page of a simulated patient care summary showing a notch cut off at the bottom right where room number and patient's last name are written and highlighted for easy retrieval. Different types of annotated information are labelled in red, e.g., diet, vital signs, and report from previous shift, showing their customized spatial layout. This summary is simulated for ethical reasons but is typical of actual summaries.

3.4.2 Information Media Types

By shadowing nurses, I identified the diversity of information media through which information is shared. As asynchronous communication is predominant during shift change in this hospital ward, correct interpretation of the information placed in the common information spaces is crucial for the accurate information flow during shift change. In the W21C, information is distributed over paper, verbal, displayed and digital media. Specifically, these information sources are: (1) digital patient records; (2) paper-based patient care summaries, patient charts containing laboratory and diagnostic results and written consults by physicians, and charge board used by charge nurses; (3) displayed shift report on large whiteboards and notices addressing the nursing staff; and (4) verbal shift report from nurses of previous shifts and instructions from the charge nurse (Figure 3.6).

Digital Media: Patients' medical information is largely digitized in the local health region using the TDS hospital information system (TDS 1960s). Most information concerning a patient's medical history and treatments can be found in the electronic health record (EHR) including laboratory and diagnostic test results. Some information such as consults by physicians and ancillary professionals can only be found in the paper-based patient charts.

Paper-based Media: Patient care summary is an abbreviated printed form of the EHR, which provides important and relatively recent medical information of a patient that the primary care nurse needs to know in order to provide quality healthcare. For example, it includes a patient's diagnosis, allergies, a brief illness trajectory, nurse to nurse communications, nursing orders, diet, scheduled medications, medications upon request, laboratory orders and instructions and consults by ancillary professionals. Each patient's care summary usually consists of several printed pages. The first page of a simulated patient care summary is shown in Figure 3.7 for illustrating typical types of information found in the summaries and their layout. Examples of handwritten annotations and visual augmentations are also illustrated in the figure.

At the beginning of each shift, fresh copies of patient care summary containing important patient information will be printed inside the shift change room. Despite the fact that these patient care summaries are printed as close to the beginning of each shift, information contained in these summaries are typically not up-to-date. To illustrate, summaries are printed out around 2:30pm for the nurses working evening shift, but outgoing nurses often have not updated the EHR before 2:30pm especially in situations where changes are expected in the patient's conditions near the end of their shift. Therefore, updated information has to be obtained through other channels.

Figure 3.8 Patient chart showing handwritten physicians' notes (image is blurred for ethical reasons)

a)

b)

Figure 3.9 Patient chart containing reports of test results: (a) ECG report showing abnormal heart rhythm (b) Cardiac MRI report showing diagnostic images (images are blurred for ethical reasons)

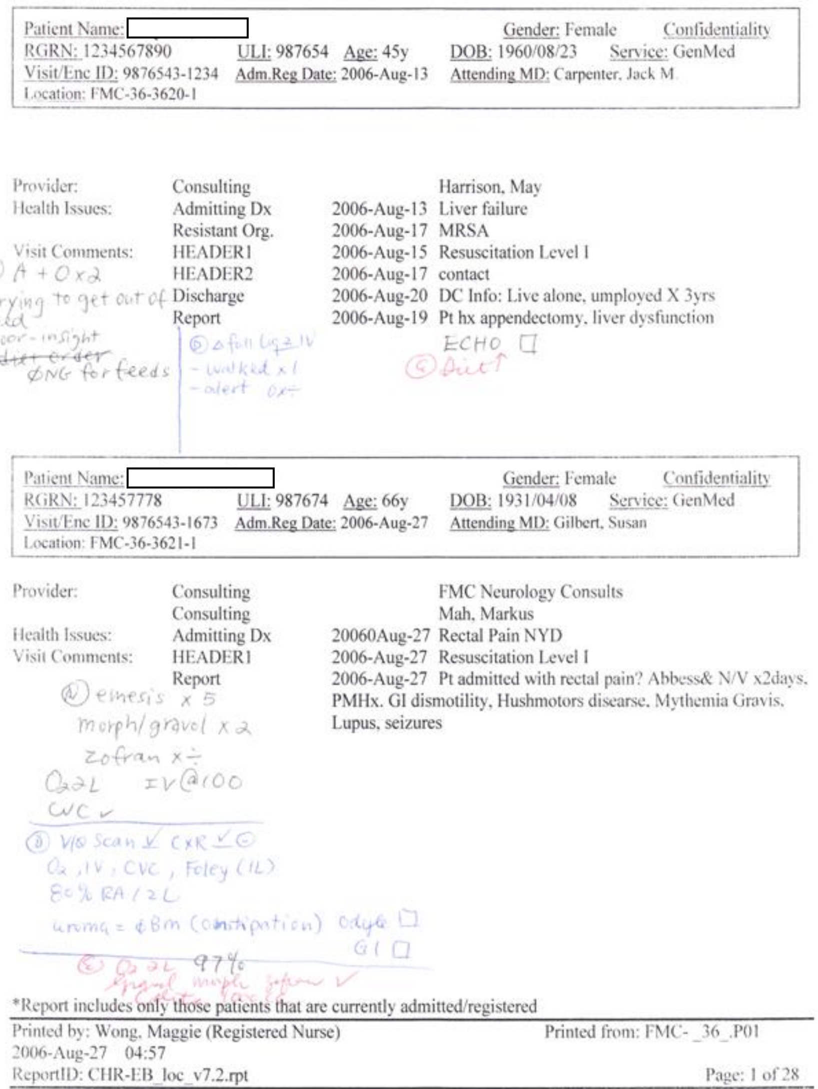
For each patient admitted to the ward, a Patient Chart is opened. This is a big binder filed with all kinds of paper documents pertinent to the patient (Figure 3.8). The chart contains color-coded tabs and pages for different kinds of information such as written consults, e.g., consults from Emergency Room, physicians' progress notes, multidisciplinary progress report (MPR) by ancillary professionals as well as communication between nurses and physicians such as orders given to nurses on duty. For example, the white page shown in Figure 3.8 contains physicians' handwritten progress notes which also often signed for easy follow-up, whereas Figure 3.9 shows two pages containing test results for the patient: (a) an ECG report showing abnormal heart rhythm (b) a Cardiac MRI report showing diagnostic images. All the patient charts are indexed by room number and are placed in a cabinet located at the back of the nursing station (Figure 3.10).

Moreover, charge nurses of each day use a different kind of printed patient information which lists the medical information highlights of all the patients currently admitted on the ward. The stack of printed information sheets is always placed on a

Figure 3.10 Reading patient chart at the patient chart cabinet in the back of the nursing station

clipboard labelled "Charge Board" (Figure 3.11), thus it is generally regarded as the "charge board". Charge nurses of the day, i.e. the day, evening, and night shift charge nurses, all use the same charge board. A fresh copy of the charge board is printed at the beginning of the day shift. The charge nurse of each shift writes down important notes on the charge board when the outgoing nurses give reports at end of their shift. A different color is used in each shift when annotating on the charge board. Figure 3.12 shows a page of a simulated charge board to illustrate the typical kinds of information it contains and the color-coded notes for each shift. Outgoing charge nurses hand over to their incoming colleague based on the annotated notes on the charge board.

Figure 3.11 Charge board contains medical information highlights for all the patients on the ward and is used by charge nurses for writing down notes during charge reporting from outgoing nurses; each page typically contains information for one to three patients (identities masked for ethical reasons)



Patient Name: [redacted] Gender: Female Confidentiality
RGRN: 1234567890 ULI: 987654 Age: 45y DOB: 1960/08/23 Service: GenMed
Visit/Enc ID: 9876543-1234 Adm.Reg Date: 2006-Aug-13 Attending MD: Carpenter, Jack M.
Location: FMC-36-3620-1

Provider:	Consulting		Harrison, May
Health Issues:	Admitting Dx	2006-Aug-13	Liver failure
	Resistant Org.	2006-Aug-17	MRSA
Visit Comments:	HEADER1	2006-Aug-15	Resuscitation Level I
	HEADER2	2006-Aug-17	contact
	Discharge	2006-Aug-20	DC Info: Live alone, umployed X 3yrs
	Report	2006-Aug-19	Pt hx appendectomy, liver dysfunction

Patient Name: [redacted] Gender: Female Confidentiality
RGRN: 123457778 ULI: 987674 Age: 66y DOB: 1931/04/08 Service: GenMed
Visit/Enc ID: 9876543-1673 Adm.Reg Date: 2006-Aug-27 Attending MD: Gilbert, Susan
Location: FMC-36-3621-1

Provider:	Consulting		FMC Neurology Consults
	Consulting		Mah, Markus
Health Issues:	Admitting Dx	20060Aug-27	Rectal Pain NYD
Visit Comments:	HEADER1	2006-Aug-27	Resuscitation Level I
	Report	2006-Aug-27	Pt admitted with rectal pain? Abbess& N/V x2days. PMHx. GI dismotility, Hushmotors disearse, Mythemia Gravis, Lupus, seizures

*Report includes only those patients that are currently admitted/registered

Printed by: Wong, Maggie (Registered Nurse) Printed from: FMC-_36_.P01
2006-Aug-27 04:57
ReportID: CHR-EB_loc_v7.2.rpt Page: 1 of 28

Figure 3.12 A simulated page of a charge board showing highlights of patient information and color-coded annotated notes made by charge nurses in different shifts

Figure 3.13 Whiteboards in the public area across from the nursing station showing nurses and doctor assignments

Figure 3.14 Whiteboards inside the shift change room for posting shift reports which are color-coded for the three shifts of the day. The column containing the last names of the patients on the ward have been masked for privacy reasons

Display Media: Large whiteboards are inside the access-controlled shift change room and are in the public area facing the nursing station near the entrance to the ward.

Whiteboards in the shift change room are divided into columns and rows for posting shift reports (Figure 3.13). Columns list the room/bed number, patient's last name, followed by reports from the day-shift, the evening-shift and the night-shift nurses in separate columns and often in different colors. Shift reports posted on the whiteboards usually contain shift-specific activities and patient information that the outgoing nurse has performed and gathered. On the other hand, whiteboards placed in the public area are assignment boards showing the nurse assignments as well as doctor assignments (Figure 3.14). Doctors of different specialties and authorities are shown in varying colors. This information is particularly important for locating specific personnel when nurses need to seek professional opinions and clarifications.

Notices are often posted inside the shift change room and in the staff room. These notices contain information applicable to the general nursing staff. At times, they contain important information pertinent to the provision of healthcare (e.g., Figure 3.15), while other times, they advertise social activities and educational opportunities (Figure 3.16). Nevertheless, they are integral to the information sharing process in the unit.

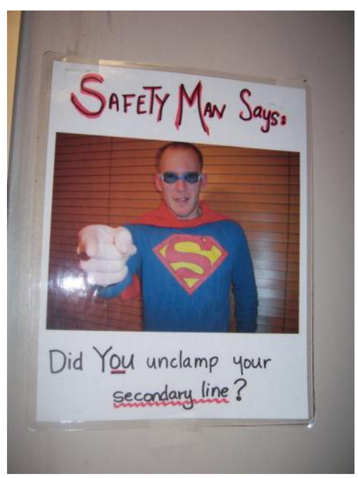


Figure 3.15 Notice displayed to promote safe healthcare practice

Figure 3.16 Notices posted inside the staff room to advertise social and educational activities

Verbal media: Verbal media in the ward represents an ephemeral common information space constructed by co-present participants to effect the information flow. Participants therefore communicate synchronously to negotiate and interpret the information in transit. While the outgoing nurse is speaking – placing audio information in the CIS – the incoming nurse will simultaneously interpret and often transpose this information to a different media in her PIS, typically a paper-based medium such as a note-sheet or an annotated patient care summary.

All outgoing nurses working in this ward must verbally report to the charge nurse of the shift unless the latter is too busy to receive reports. In that case, outgoing nurses will write a brief report on the charge board (Figure 3.11) as a contingent alternative. This charge reporting is important so that the charge nurse on duty will acquire information of each patient and an overall knowledge of the ward. As a result, the outgoing charge nurse can then hand the information over to the incoming charge nurse.

As verbal reporting between nurses working in consecutive shifts is not mandatory, the observations reveal that this reporting medium is discretionarily used, especially when the outgoing nurse has already updated the whiteboard inside the shift change room. Some nurses give a verbal report even after they have updated the whiteboard to make sure that their incoming colleague interprets the displayed information as intended. Most nurses, however, do one or the other, unless the incoming nurse specifically asks for a verbal report as well.

3.4.3 Information Content and Function Types

The physical artefacts, specifically the personal notes, which were collected during the study, were examined to find out what content and function types of information are used. I found many similarities in the kinds of information extracted from the various information media. These information types help answer the questions about information content and purpose. However, the information types that I have identified may not be exhaustive and a given piece of information may fall into one or more of these categories. Appendix B.2 tabulates the information contents extracted from the collected personal notes and the codes generated which forms the set of information types described below. Figure 3.17 shows some simulated personal notes annotated with letters for illustrating the use of the identified information functions which will be described below.

Demographics list a patient's name, age, gender, room/bed number and caring physician (Figure 3.17, A - in which a symbol is used for gender). The interviewed participants who did not use separate personal notes explained that transposing their patients' demographic information into the note sheet was too labour-intensive to do manually.

Historical Information includes a patient's past medical information such as initial diagnosis, treatments performed and their illness trajectories (B - for diagnosis at admission).

Reminders and To-Dos serve as *aide memoires* such that action has to be taken by the participant. These may appear singly or in groups and are usually attached with a temporal marker, for instance indicating that a task needs to be performed at certain time

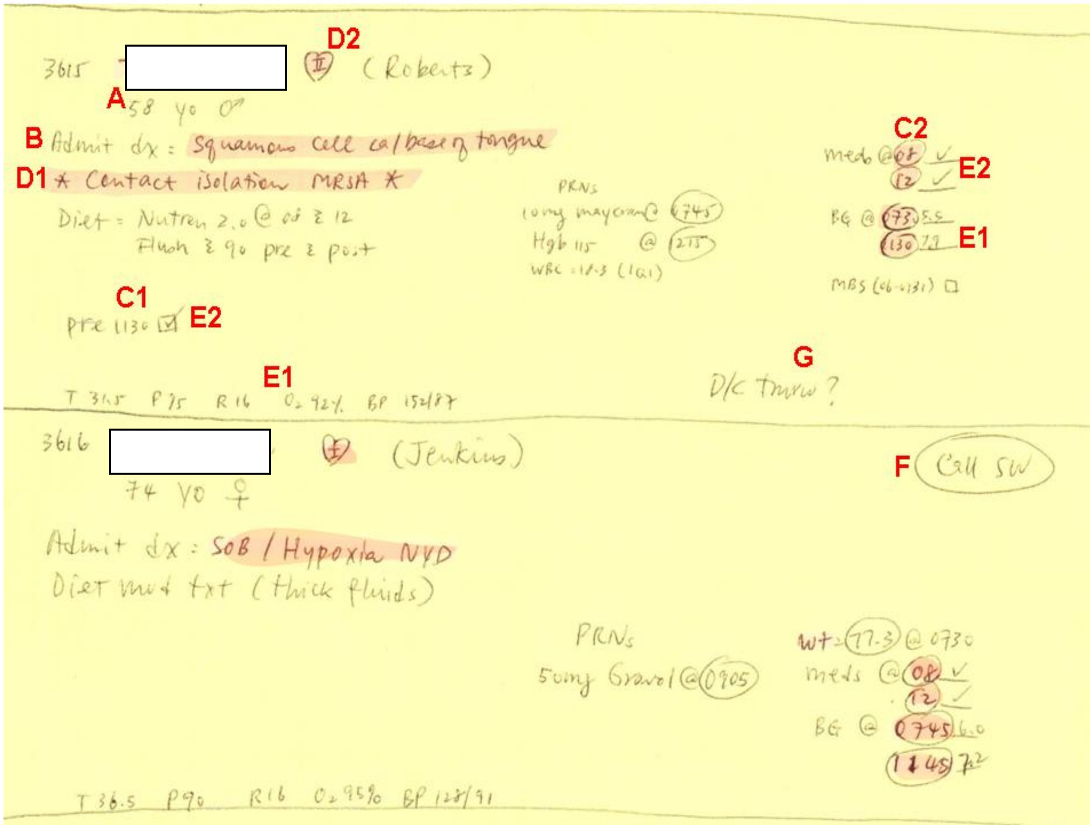


Figure 3.17 Simulated personal notes to illustrate typical information function types and their customized spatial organization (patient names masked). Red typed letters are labels to aspects that are explained in the text.

or time interval (C1 - indicating the patient's appointment with a physiotherapist at 11:30am, and C2 - the times for administering medicine and measuring blood glucose).

Alerts are often intrinsically historical information that directly affects the well-being, and more importantly the survival of a patient. Examples of this include specific allergies, isolation status (e.g., D1 – "*contact isolation: MRSA*") and resuscitation level such as DNR for do not resuscitate (e.g., D2 – resuscitation level 2 enclosed inside a heart symbol for alerting that the patient does not want any CPR although the patient may agree to intubation and be sent to ICU).

Prompts are personally created information place-holders. These come with a variety of information buckets (e.g., text lines and/or checkboxes) that require participants to fill in information while at the same time serving as memory triggers (E1 with text lines for filling in measurements). They are also used as status indicators showing if a task has been accomplished (E2).

Scheduling information is information that participants must seek to arrange with third parties such as physiotherapists, occupational therapists or social workers for the patients (F – to schedule an appointment with social work for the patient). This kind of information is often less time-sensitive than reminders and to-dos.

Reporting information is gathered during patient assessment and needs to be reported to the next shift or other pertinent personnel. For example, changes in treatment progress must be reported to the responsible physician and any variation in a patient's well-being must also be reported to the next caring nurse (e.g., E1 on the right if the blood glucose levels appear to be out-of-ordinary).

Verification information often comes with a question mark as a reminder to seek clarifications for a particular issue. For example, "discharge tomorrow?" (G) affects bed management on the ward and arrangement for the patient's out-of-hospital care.

3.4.4 Types of Information Spaces

During the study I observed the use of both common information spaces (CISs) and personal information spaces (PISs). The common information spaces are well aligned with Schmidt and Bannon's definition – "encompasses the artefacts that are accessible to a cooperative ensemble *as well as* the meaning attributed to these artefacts by the actors" (Schmidt and Bannon 1992). A personal information space differs only in that the information space is owned and manipulated by a single individual.

3.4.4.1 Common Information Spaces

It was observed that cross-shift communication between nurses and inter-disciplinary communication in W21C is predominately asynchronous and largely conducted by distributed collaborators. By ‘distributed’, I mean collaborators who are temporally and/or spatially separated making face-to-face communication unlikely. For instance, nurses of consecutive shifts do not usually meet to communicate, doctors are not often in the ward but when they are they write down instructions to nurses in a patient chart, and ancillary professionals operate similarly to doctors in that they also write on the patient charts. These CISs constructed by this temporally distributed team are characterized by a high degree of closure in that people do not dispute entries. However, the medical data recorded remains dynamic in that their meaning may be continually changed by additions and re-articulated comments. This observation agrees with Jirotka et al.’s (2005) discussion. These types of CISs were externalized through some kind of coordinative physical artefacts, e.g., a patient chart and the electronic health record. The information set, in particular medical assessment and treatment information, is constantly being generated by a wide range of collaborators including doctors, ancillary professionals and outgoing nurses during their shifts. This information set plays the crucial role of input for the next shift as well as for the other health professionals, enabling continuing patient care. Collaborators achieve the information flow by packaging and placing the information (with intended meaning) in appropriate CISs so that the information can be shared among concerned personnel. To do this, outgoing staff often rely on some form of personal artefacts which will be discussed in more detail in the next subsection.

Although less frequent, nurses across shifts are sometimes co-present to communicate during shift change. The CISs are then constructed through a combination of verbal and gestural communication. For example, while Lily explained a patient’s condition, she gestured to a location on her own body to indicate where the patient had a wound during the verbal report to her next shift. Such a verbal CIS is highly open and malleable for immediate clarification when ephemeral information is misinterpreted.

Interviews with the participants indicated that communication may break down when the interpreted meaning deviates from the intended one, especially when clarification is not possible. Consequently, incidents such as inappropriate care may be performed as a result.

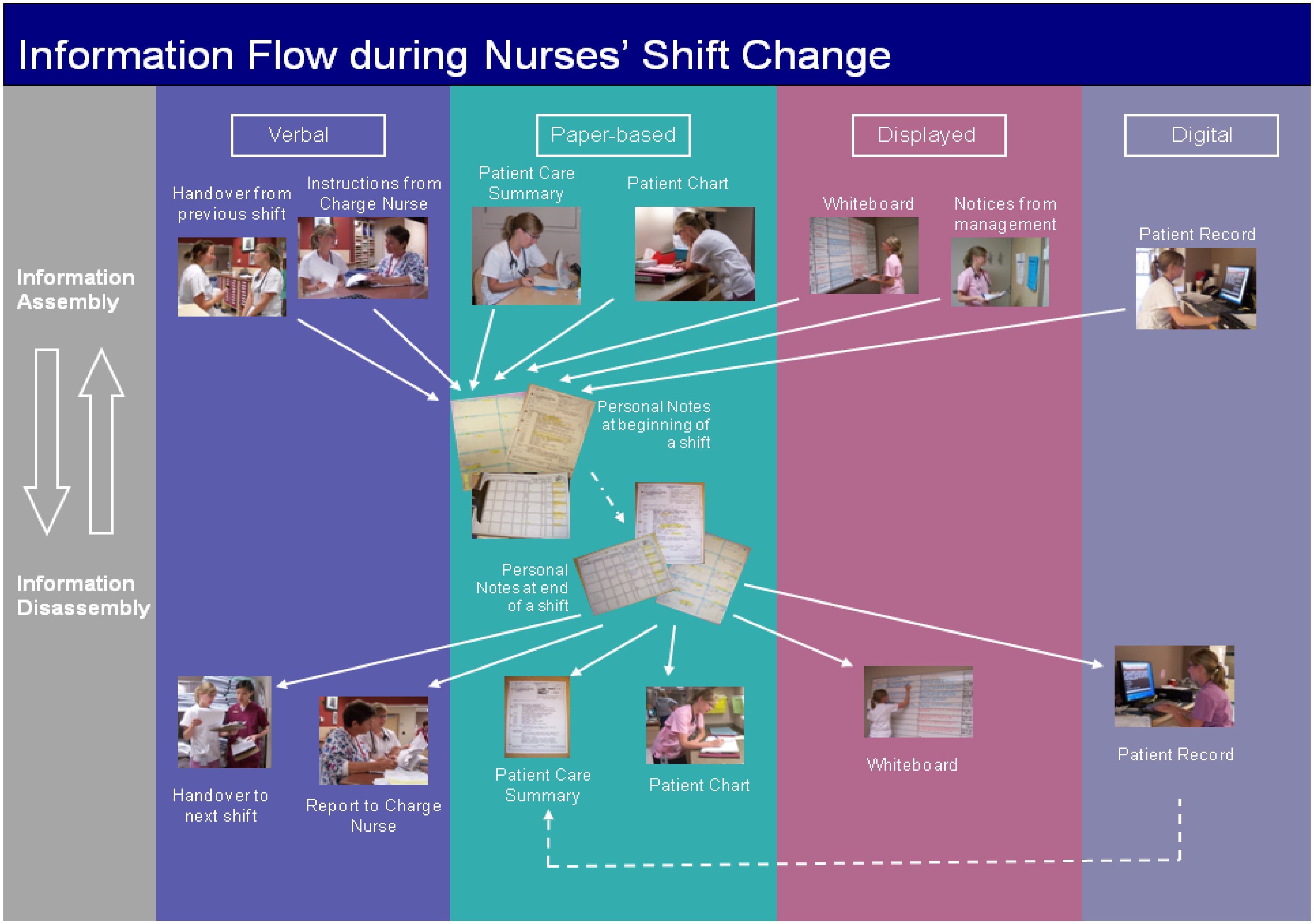


Figure 3.18 Information assembly and information disassembly activities performed in parallel during shift change

The CISs that I have observed are jointly constructed by participants, making use of coordinating artefacts and the attached meanings derived from a diversity of information sources. These CISs are maintained and enriched continually with the latest medical information that is important to ensure smooth and continued provision of healthcare services in the ward. I now turn the attention to the PISs that play a crucial role in bridging between work in progress and the CIS of pre-shift and post-shift

3.4.4.2 Personal Information Space

I observed personal information spaces (PISs) being actively constructed by incoming nurses at the beginning of their shifts. As information was gathered from the CISs (Figure 3.18 top), it was first interpreted and then transposed to the nurses' own PIS. These PISs typically involved the use of a physical artefact such as a note sheet. In practice, individuals use a combination of physical artefacts and mental capacity as the constituents of their PISs. For example, 7% of the participants used the previous shift report by committing it to memory. The PIS is constructed at the beginning of the shift then during the shift it is dynamically re-configured with additions, annotations, and deletions, and is actively used to facilitate the performance of tasks during a shift (Figure 3.18 middle). At the end of a shift, information gathered during a shift and stored in the PIS (including both physical artefacts and mental capacity) will be contextualized and organized for dispensing into appropriate CISs (Figure 3.18 bottom). As such, the personal notes are found to serve as the primary coordinating artefacts to facilitate task performance during a shift.

The physical artefacts collected in the study were examined. It was found that they are largely composed of a variety of information types in terms of content and function (Section 3.4.3). The coordinating physical artefacts created and used by the participants are also found to be highly individualized with generous use of visual attributes (Figure 3.17 and 3.19). A wide range of visually attentive objects and features are used to make the information carried by these objects and features to stand out. Pre-attentive features such as text orientation, spatial clustering, added marks, unique symbols, color-coding and 2D spatial position (Ware 2004) were generously used to

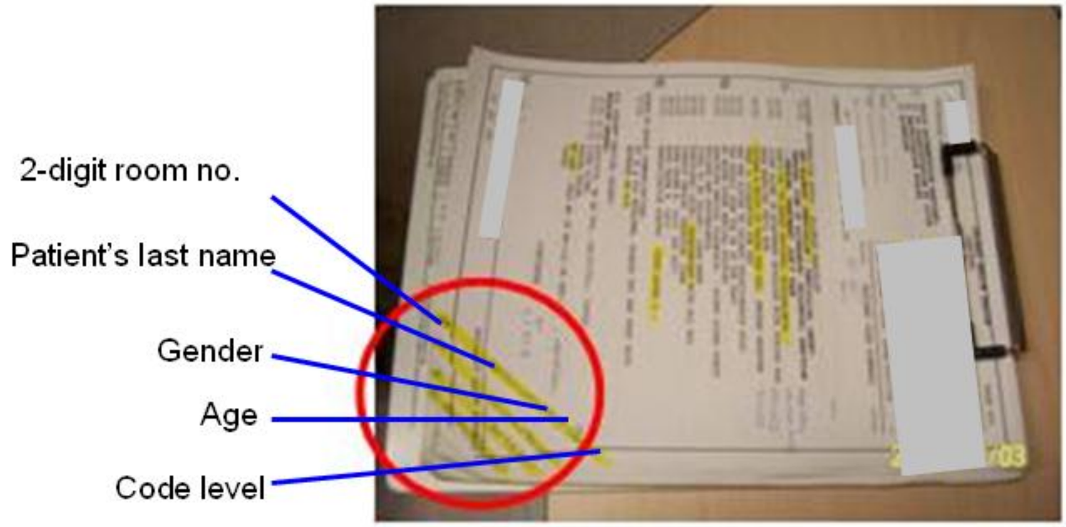


Figure 3.19 The bottom right corners of several patients' care summary are cut with staggered notches as tabs, along which 2-digit room number, patient's last name, gender as a symbol, age and their code levels are written and highlighted for easy retrieval (circled)

represent different content and function types of information (see Section 3.4.3). They also employed physical attributes such as staggered notches that were cut off the bottom-right corner of their stack of patient care summaries so that each patient's record stands out for easy retrieval (Figure 3.19). When nurses created their own personal artefacts, all the notes were written and visualized on a single page of paper.

Moreover, the observations and interviews both indicated that the nurses have their own spatial arrangement for different types of information when creating their personal artefacts. For example, Figure 3.17 shows the personal notes for two patients in which demographics is placed in the top left corner of the notes for both patients (A), followed by the diagnosis at admission (B), whereas the vital signs are place at the bottom along the dividing lines and the to-do list such as medication administration and lab measurement activities are placed near the right side of the notes.

Specifically, all the participants using separate personal notes and almost 90% of the participants who used an annotated patient care summary have a habitual spatial organization and layout of information. The spatial plan serves as a spatial memory trigger that helps when they look for a particular kind of information. This is particularly important when they are carrying out time-critical activities. As said by an experienced nurse, "*my sheet [personal notes] may seem very messy, but I know exactly where to look when I need a particular piece of information.*"

3.4.5 Types of Information Processes

Information flow across shifts was observed to be dominated by two processes that take place in parallel: information assembly by incoming nurses (Figure 3.18 top row) and information disassembly by outgoing nurses (Figure 3.18 bottom row). Another significant information process I observed is the temporal coordination between information assembly and disassembly.

3.4.5.1 Information Assembly

I define information assembly as a collective process involving a series of activities for seeking information from a multitude of spatially-distributed information sources. (Figure 3.18 top row). An incoming nurse starts a shift by physically moving around to seek information from information sources in different locations. To illustrate, an incoming nurse often starts inside the shift change room to extract information from the patient care summaries and the whiteboard. She then moves to the nursing station where patient charts and electronic health record (EHR) may be accessed. Verbal instructions/reports from the charge nurse/previous shift nurse may also be obtained here or at other locations inside the ward. Afterwards, she goes to the ward wing where her patients stay. She may then retrieve the EHRs from the computers located along the corridors (see Figure 3.3a). In addition to the information sources being spatially separated, most of them are mobile. Thus they may at a given moment have been temporarily removed from their designated location by other nurses or other health professionals. Such mobility may accentuate the complexity of the information assembly process when the information seeker needs to first track down the location of the information sources before she can seek and assemble information from the sources. This process is further complicated if the incoming nurse needs to assemble information from personnel not included in Figure 3.18, e.g., physicians and ancillary professionals. This information assembly process may be regarded as completed when sufficient information has been gathered for the shift work. Yet, in practice, the completion of information assembly process may not be as crisp depending on if there are pressing issues that require the nurse's immediate attention.

3.4.5.2 Information Disassembly

Information disassembly is primarily the reverse process to information assembly. To disassemble the collected information gathered during their shift, outgoing nurses have to move spatially to each information artefact (Figure 3.18 bottom row). They organize their own notes, predominately mentally, and then disseminate the information to appropriate information artefacts in a way that they believe will be understood by their intended readers. The outgoing nurses were found to rely heavily on the contents placed in their personal notes when disassembling the collected information back to the information repositories (these are the information sources during information assembly). Current routines at the end of a shift include updating the patient chart, updating the electronic health record, posting a shift report on the large whiteboard and/or verbally reporting to the next shift, as well as verbally reporting to the charge nurse. Unlike the information assembly activities, some information disassembly activities may be performed well before the end of a shift, especially when no changes are expected in a patient's condition or treatment. The completion of the information disassembly process is usually more clear-cut, often marked by the nurse disposing of their more ephemeral personal artefacts.

3.4.5.3 Temporal Coordination

In the observations, I found no specific order by which the information assembly and information disassembly activities were performed. While the incoming nurses typically start by seeking information from the patient care summaries and the shift report on the whiteboard, if available, there is no specific order in which they seek information from other information sources. Similarly, the outgoing nurses described that the order of performing the information disassembly activities largely depended on the preference of individual nurses, their workload and the availability of concerned personnel.

To achieve the information flow across shifts smoothly, information assembly and information disassembly are not two separate standalone processes. Rather, the process of information assembly is temporally dependent on the information disassembly process and they have to be temporally coordinated within a brief time frame during shift change (McGrath 1990). Otherwise, the information flow may be broken, at least temporarily, and other contingent practices which usually require more time and extra effort to be undertaken. For example, an incoming nurse needs to find out what has taken place in the previous shift(s) and such information should be displayed on the large whiteboards inside the shift change room. However, if the outgoing nurse did not update the board in time, the incoming nurse will then have to look for the outgoing nurse and ask for a verbal report. However, if the outgoing nurse cannot be reached, the incoming nurse will have to either ask the charge nurse, or look up the electronic health record which may contain the required information. From the interviews, the participants expressed that their knowledge and familiarity with their colleagues' practices helped coordinate the information seeking process. For example, Nancy knows that the nurse working the previous shift, Greg, often writes a very brief shift report on the whiteboard and prefers a verbal report. She then always expects a detailed shift report when Greg 'hands over' the patients to her. This finding agrees with the 'biographical familiarity' identified in Jirotka et al. (2005).

3.5 Design Implications

This study found that information flow during shift change involves a rich set of information, media, and locations. Computer technology may have a good potential to improve the situation by replacing and/or supplementing some existing technology in a manner that may offer a more coherent and comprehensive information ensemble. Although it may be premature at this point to design technology to support the practical work during shift change, the findings from this study offer implications for the design of technologies for enhancing the information flow in the specific medical setting.

3.5.1 CIS and PIS Interaction

Understanding the nuanced interaction between the common information spaces and the personal information space can help inform the design for preserving and managing their use and ownership. It is important to understand the characteristics of the CISs and the roles they play in the information flow (Randell et al. 2008). As some CISs are constructed by a wide range of personnel, we must also consider their use of artefacts if these spaces are to be augmented with technological support. Similarly, we need to consider how PISs can be supported with technology without requiring extra effort from users to maintain both information spaces.

3.5.2 Consistency of Language and Terminology

Common information spaces are shared among clinicians who come from different disciplines to communicate with each other in order to provide quality patient care. Thus their use of language, terminology, symbols and notations may also vary. Communication can thus easily break down when the interpreted meaning of information, such as abbreviations used, inscribed in the shared information artefacts (i.e. CIS) deviates from the intended one. Therefore, use of agreed upon language and terminology within supporting technology could help reduce miscommunication.

3.5.3 Customizability of PISs

As all the nurses create and customize some form of personal notes which then serve as the primary coordinating artefacts for facilitating task performance during a shift, these personal artefacts justify a closer examination. For instance, any technology considered should allow nurses to customize their personal information space and to include interaction mechanisms. For example, the technology could provide a choice of visual elements that support pre-attentive processing, and allow positioning of information by using such things as spatial clustering or orientation. Also, since rapid indexing and retrieving of information is currently manifested in all observed PISs, some facility for this is another important feature to include in technological support. For instance, the personal information space could be completely visible or incorporate some intuitive indexing for easy retrieval of patient information.

3.5.4 Support Redundancy

With the multiplicity of information artefacts involved during shift change, it is not surprising that redundancy may exist. For example, information conveyed through verbal reporting may also be available in the shift report displayed on whiteboards. However, such redundancy may perform some type of backup function and the complementary artefacts may provide for more comprehensive information. Therefore if and how such redundancy should be eliminated (Cabitza et al. 2005) and how the rich information provided through complementary artefacts can be upheld should be investigated.

3.5.5 Introduction of Technology

Information assembly and disassembly processes are complicated due to the varied information sources and their spatial distribution. At first glance, individual information sources may be replaced by innovative computational devices to enhance the efficiency during shift change with minimal impact on current work practices. For instance, large digital boards may replace the existing whiteboards. The mobile and dynamic nature of nursing work also appears a good candidate for mobile technology so that nurses may remain at the point of care while retrieving and documenting pertinent records. Timely and up-to-date patient assessment information would then be available for incoming nurses who then need not expend extra effort to seek this information. Instead, they can spend more time with their patients. In fact, the use of portable devices in clinical settings has been found to reduce the time spent in documentation and the patient outcomes and safety are also improved, while communication errors and omissions are reduced with the employment of point-of-care documentation (Strople and Ottani 2006). Thus we should look into the possibility of introducing mobile technology at the ward. We may also consider context-aware technology by embedding the information processing devices into the environment more naturally and casually as a means to ease the mobility issues (Bardram 2004).

It is intimidating to design technologies to encompass the richness of existing practices of information flow in information-critical medical settings. Yet, we envision nurses being able to acquire information they deem important from the multitude of information spaces and visualize the collected information in their desired representation alongside a range of desirable interaction mechanisms.

3.6 Discussion

Previous research typically described shift change as a linear process of outgoing nurses handing information over to their incoming colleagues (Section 2.2.2). In contrast, our observational study identified that a pair of parallel processes - information assembly and information disassembly - took place concurrently within the brief duration of shift change. Previous studies mostly focused on the single "handover" activity, e.g., verbal or written exchanges (Section 2.2.2). Our study revealed other important activities, such as actively acquiring information from information artefacts that are integral to the shift change process. Previous studies recognized the use of paper personal artefacts in information flow (Section 2.3.4), we added to this by detailing how the information contained in these artefacts impacted the information flow and work practices. Finally, prior work did not identify the interplay between the common information spaces and the personal information space in the information flow. We discuss information flow in terms of the interplay between these information spaces to inform the design of supporting technologies.

3.7 Chapter Summary

I have conducted an observational study at W21C to investigate how information flow took place during shift change. This study is one step towards my goal: to design and develop a technology prototype that will appropriately support the practical activities and actions that take place during shift change.

I have identified a rich set of spatially-distributed information sources with which nurses are required to interact for both assembling and disassembling information. These processes of information assembly by incoming nurses and information disassembly by outgoing nurses during shift change have been shown to be a complex task. It is complex because (1) it involves a variety of media: paper-based, verbal, displayed and digital sources; (2) these media sources are distributed over spatial locations such as the shift change room, the nursing station, the computer room and the four wings in the ward; and (3) the information assembly and disassembly activities take place almost in parallel within a brief time period. Spatial movement across different information media and subtle temporal coordination are therefore required to ensure that information is available at the right place and at the right time.

I also observed participants spatially arrange information on the personal artefacts and how such arrangement complements the information types identified to facilitate the manipulation of their PIS. The results, confirmed by follow-up interviews, showed that 39 out of 40 participants have a regular practice of spatial organization and layout of information to help them locate information in their PIS.

Finally this in-depth observational study helped inform a set of design implications that should be considered when designing technologies to support information flow during nurses’ shift change. They include the interplay between the common information spaces and the personal information spaces, the use of consistent terminology, the customizability of personal information spaces, the support for redundancy, and the impacts of technology introduction to the workplace.

Chapter 4. Evaluating the Deployment of a Mobile Technology

The previous chapter presented an in-depth observational study of the information flow practices taken place during nurses' shift change, in which a legacy electronic health records (EHRs) had been in use to provide distributed information access by clinicians. However digital information was only available at stationary desktop computers at the nursing station, along ward wings and in the computer room in the study ward. Therefore, a technological setup was deployed in the study ward by the hospital to allow information access and data entry at points of care. The deployed technology consists of wireless mobile computers (computer-on-wheels) and a new digital information system. I was unaware of this deployment plan until about three months after the completion of the first observational study although the deployment had been planned by the health authority before this research commenced. Nevertheless, I considered it an excellent opportunity to conduct a third-party study to investigate how this mobile technology would benefit or impede the nurses' work practices around information flow using the knowledge gained from the first observational study presented in Chapter 3 as baseline resource.

The hospital's long-term goal of deploying this mobile technological set-up was to achieve a paperless hospital ward whereas the short term goal was to reduce the use of paper artefacts, specifically the printed patient care summaries and the paper personal notes, in the daily clinical work. I was thus also interested in finding out whether the mobile technology was successful in replacing the use of these personal paper artefacts which nurses had previously relied upon for carrying out their nursing tasks. Thus, the new information flow as expected by the hospital is represented in Figure 4.1.

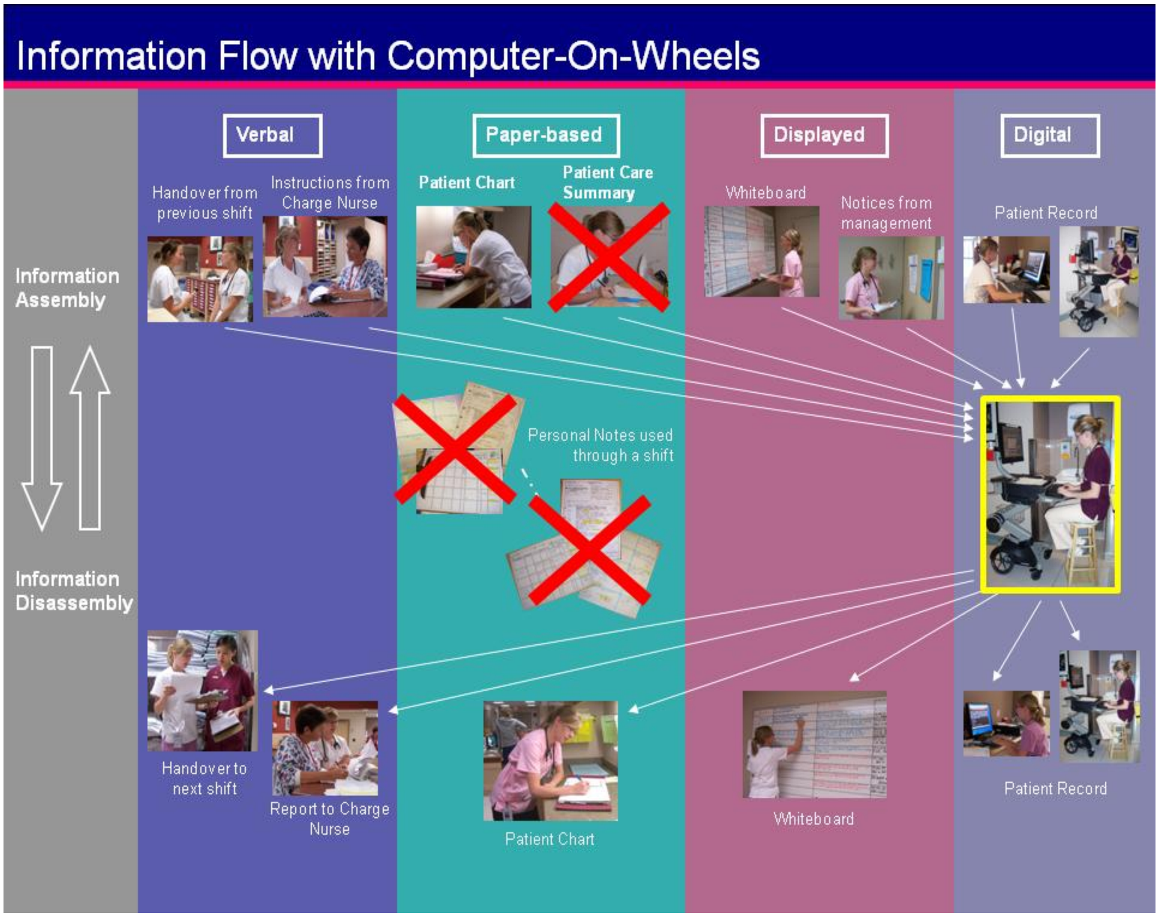


Figure 4.1 The information flow with the deployment of computer-on-wheels expected by the hospital

In the remainder of the chapter, I first describe the technology deployed in the ward. Next, I describe the study in detail and report the findings. I also discuss the impact of this mobile technology on the use of paper personal notes in nursing work. Finally, I conclude with a description of design suggestions for supporting mobility in the hospital setting.

4.1 The Technology

The technological setup deployed in the study ward consists of wireless mobile devices (computer-on-wheels) and a new patient care information system. The focus of this study was to investigate the impact of the deployment of these mobile devices. First, I provide

Figure 4.2 Nurses working at wireless COWs in their ward wings

brief description of the new digital information system.

The mobile device, computer-on-wheels (a.k.a. COW), is a desktop computer placed on an ergonomically designed mobile cart running on a wireless network to provide mobile access to the EHR. These computers-on-wheels allow clinicians to access patients' medical information, including high-resolution digital images, laboratory results, and medication histories, at their bedside with a few mouse clicks. The input is primarily provided via keyboard entry and mouse manipulation. The height of the cart, i.e. the height of the keyboard, is slightly adjustable for standing or sitting on a high stool (Figure 4.2).

The new patient care information system consists of the EHRs (Figure 4.3) and online resources. The EHR is built upon a hierarchical structure offering patient-centric clinical information such as medical and nursing orders, medication administration records, vital sign documentation, and viewing of diagnostic images and lab test results. Each screen contains specific information pertinent to a patient's health conditions. For example, Figure 4.3 shows an interface displaying a patient's laboratory results in which the red arrows indicating an increase or a decrease in the measurement of particular tests. Navigation through mouse-clicks to other screens is required to access other kinds of information. Online resources provide access to references such as medical dictionaries, and nursing handbooks for, e.g., drug-drug interactions and contraindications.

Figure 4.3 An interface of the new electronic health record which is a hierarchical information system. Each screen displays specific kind of information. The interface shown here displays a patient's laboratory results, the up and down red arrows near the centre column indicate out-of-range, either higher or lower than the norm, lab test measurements. (Identity information is masked and content is blurred for ethical reasons)

4.2 Methodology

This observational study on the use of computer-on-wheels was conducted in two stages: at two months (early-stage) and at eleven months (late-stage) after the technology was deployed. We conducted this study at two different time frames because difficulties are typically experienced in the early adoption of new technology, it is important to distinguish short- and long-term difficulties. The former will typically be resolved on its own, while the latter may require intervention for improvements. Moreover, the findings from the first observational study presented in Chapter 3 were used as baseline reference for identifying changes in the early stage of this study.

Participants in the two stages varied slightly due to shift assignments, staff vacation, and turnover; however the study design allows us to uncover short- and long-term phenomena to reveal how the technology was adopted and how it could be improved.

4.2.1 Study Method

In both stages of the observational study, I used minimally intrusive observations, informal interviews and examination of the information artefacts to investigate how nurses used the mobile device for information flow during information assembly and information disassembly as well as during shifts and to explore if difficulties were encountered. Informal interviews were conducted when clarification and elaboration of their actions were needed and when the situation allowed.

I completed the study with a questionnaire survey. The purpose of the survey was to gather qualitative and quantitative feedback from participants regarding the benefits and drawbacks they experienced from the technology after using it for almost a year. I provided the questionnaire in the staff room during participants' meal breaks. Respondents voluntarily participated in completing the questionnaire. No personal identification information was asked in the questionnaire and the completed questionnaires were randomly put in a large envelop to preserve their anonymity. All 29 questionnaires handed out were received. Each participant spent about 15 minutes on the questions which consisted of a variety of multiple choice questions, and some short and longer answer open-ended questions. The multiple choice questions gathered specifics such as before and after preparation times, while the open-ended questions gave participants space to declare reasons and explanations. For example, we asked *"Given a choice, which computer do you usually use to prepare medication? Why?"* and *"Do you encounter problems when using a COW? What kind of problems and how often do you encounter them?"* The complete questionnaire can be found in Appendix B.3.

4.2.2 Analysis Method

For this analysis I used three steps. First, open coding was used to analyze the data collected from the early stage, using the findings from the previous chapter as benchmarks. Second open coding was used again to analyze the data collected from the late stage using the findings from the early stage as reference. Finally, the questionnaires were analyzed by tallying and quantifying the closed-ended questions and looking for similarities and differences in the responses to the open-ended questions.

4.2.2.1 Analyzing first-stage observational data

Open coding was used to analyze the field data collected in the first stage to identify the changes in the nurses' information flow activities during and across shifts as a result of the technology deployment. The findings from the study described in Chapter 3 were used as benchmarks for comparison. An initial set of codes was first established from a preliminary understanding of the field data after the data was collected but before it was rigorously analyzed. This initial set of codes included some of the codes used for analyzing the baseline study. For example, activities such as [VREPORT] for "verbal reporting" and [RNOTES] for "referring to personal notes" were common in both studies. I then went through all the field notes, where I assigned these codes to the observed events. Each event could be assigned with multiple codes and the codes were used to mark any reoccurrences of similar events. New codes would be created if existing codes did not fit the event. For example, [LONELY] was not present in the initial list of codes but was needed to describe the emotional response of our participants in the early stage of the second study. The codes generated were then examined and similar ones were grouped into themes. For example, since [HAND SWITCH] – switching hands between pen and mouse and [CROWDED WSTATION] –computer workstation too crowded were all resulted from ergonomic design issues, a new code [ERGONOMIC ISSUE] was then assigned. A list of codes for the study can be found in Appendix C.1 where the column “Codes I” are the final low-level codes and “Codes II” are the final high-level themes.

4.2.2.2 Analyzing late-stage observational data

Similar opening coding technique was used to analyze the data collected from the late-stage observations. We used the low-level codes listed under “Codes I” in Appendix C.1 as the initial list of codes for the late stage analysis to find out if the difficulties and benefits identified in the early stage were still present, improved, or worsen and if there were any newly emerged difficulties or benefits. For example, nurses were found to subconsciously rush when preparing medications in the early stage [RUSH MEDS PREP] was found to be dealt with moving the mouse to reinstate the timer for power-save mode in the late stage, so a new code [WORKAROUND TO POWER SAVE MODE] was created, which was then themed as an [IMPROVEMENT] in the second iteration of the coding. Appendix C.2 displays a list of codes for the data collected in the late stage.

4.2.2.3 Analyzing survey questionnaires

The close-ended questions of the survey were counted for each response received and were expressed in simple statistical terms such as means and standard deviations. Open-ended answers were tabulated for each question. Similar ones were grouped and the frequencies were noted. More detailed findings can be found in Appendix C.4.

4.2.3 Participants

In the early stage, study participants were 2 patient care managers, 35 registered nurses, and 1 nursing student. In the later stage, study participants in the observations were 1

(a) (b)

Figure 4.4 (a) Nurses preparing for their shift while socially interacting inside the shift change room before deployment of the COW (b) the computer room (a.k.a. physicians' area)

patient care manager, 24 registered nurses, and 2 nursing students. 29 nursing staff participated in the survey.

All the participants were working on the ward at the time of the study. All the questionnaire respondents had personal experiences in retrieving and entering information in the EHR. Since the participants use the technology to fulfill their job, they were highly motivated to provide feedback and their personal experiences with the technology.

4.3 Findings

With the deployment of the new technology, the electronic health record of the new digital information system became the primary information source and repository for nursing care. Nurses no longer assembled inside the shift change room during shift changes as before the technology deployment, as shown in Figure 4.4a. Instead, they prepared their shift at a computer, either at a wired desktop computer or a wireless COW. Given a choice, most of them would use a desktop computer inside the computer room. However, due to organizational design, nurses can only use the computer room during night/day (~7am) and evening/night (~11pm) shift changes because physicians generally occupy this space during day/evening shift change (~3pm). Thus this space is commonly referred as the "physicians' area" (Figure 4.4b). Nurses might sometimes work at a desktop computer in a ward wing; they would have to either stand or sit on a high backless stool to use these machines (Figure 4.2).

4.3.1 Early Stage of Technology Deployment

In the early stage of the technology deployment, nurses were highly encouraged to use the COW for information access and entry although stationary desktop computers were still available along ward wings and inside the computer room. They were also motivated to experiment with the new technology as they believed that the technology could help improve their work performance. Yet, several undesirable impacts as a result of the technology deployment were observed.

4.3.1.1 Virtual mobility

The COWs were designed to be mobile with the ergonomically designed cart so that they could be easily moved for use at different points of care. However, only one of the nurses in the observations would always bring a COW into patient rooms and enter medical information directly to the EHR without first transposing to her note sheet. Yet, she still kept a personal worksheet of important medical information with her as a reminder and as quick reference. All other nurses said they rarely brought a COW to points of care because of its bulkiness and clumsiness. Also, the computer screen and keyboard did not provide the same affordances as paper and pen which offered a convenient personal information space to facilitate the nurses' work. With paper, they could easily and quickly jot down notes whereas with the COW which is a common information space shared among clinicians, they first had to log on and to navigate to the right screen of the information system, then type information in the rigidly formatted fields in a way that was acceptable for sharing with other clinicians. They found this activity too time-consuming. Therefore they would first write information down on their personal notes and only enter it into the EHR when they had time or at the end of their shift.

Moreover, many rechargeable batteries wore down so quickly that a sign "IMPORTANT! Plug in Cart When Stationary!" was posted at the top of all the COWs as shown in Figure 4.5. Therefore, scenes like Figure 4.6 where the COWs were plugged to the wall along hallways for recharging were common. Some nurses found this tedious and time-consuming. An experienced nurse commented, *"Recharging the COW is not a priority of my job!"* Therefore the nurses were generally hesitant about using the COW due to the additional overhead required.

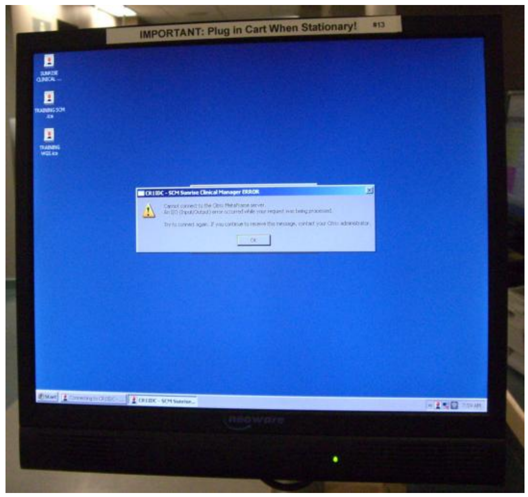


Figure 4.5 A sign "IMPORTANT: Plug in Cart When Stationary!" posted at the top of the monitor to remind nurses to plug in the COW

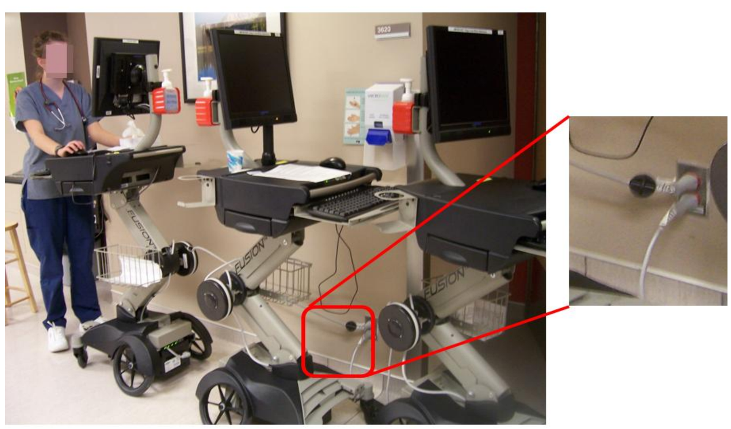


Figure 4.6 COWs plugged to wall outlet in hallway

4.3.1.2 Less time for patient care

The patient care summary which was used before the adoption of the COW was an abbreviated EHR containing updated patient's medical information at the beginning of each shift. Nurses had usually been able to get a good grasp of their patient's condition and to develop an adequate shift-specific nursing care plan for each patient after reading the patient care summaries and the displayed shift report on whiteboards, while more detailed information could be found in the digital record during information assembly (Tang and Carpendale 2007a). However, the new EHR always displayed the patients' complete medical information. Thus, the time required to read through the extensive record was considerably longer. This was exacerbated by the large number of finely specialized categories of information residing in specific windows in the new information system that they had to navigate to the right screen before finding the necessary information. All the nurses observed required more time with the new system; several nurses commented that they needed twice as much time as before.

Similarly, outgoing nurses needed more time during information disassembly to chart new information into the EHR as they were not yet familiar with the new system and the deep hierarchical information structure also complicated the process. I observed a nurse trying to chart the nutritional intake of a patient. She could not remember where the information should be placed. She asked another nurse who was nearby. They tried the keyword search for "nutrition", "diet", and "food intake", but none was right. The nurse then decided to just put that information as part of the online nurse-to-nurse communication so that at least the incoming nurse would know about the information.

With the increased time needed in both preparation and charting for a shift, there was less time left for delivering patient care unless the nurses stayed behind after their shift. Indeed many nurses stayed longer during the observations.

4.3.1.3 Possible compromise of patient care

With the known volatile battery life and a concern for confidential patient information being disclosed if nurses forgot to log themselves off the system, the COWs were set to run on power-save mode such that the system would turn off automatically after a few minutes' idling. This has proved to be a considerable challenge for nurses when they were preparing medications. The monitor displayed medication information while nurses prepared them at a medication cart (a.k.a. med-cart). Nurses always placed a COW beside a med-cart (Figure 4.7a). Their hands were usually occupied with medicine and apparatus such as a syringe and while the computer remained idle in terms of input, the nurses were following the on-screen information. Therefore, the fear of getting logged off by the system often compelled the nurses to subconsciously rush to complete the preparation. This is because each time they were logged off, not only would they need to log on the system again, they also had to manually navigate to the right screen before they could continue the task. Such unintentional hasty behaviour unfortunately can be prone to adverse events, in particular, medication error which has been found to be one of the most common preventable non-operative (i.e. non-surgical) adverse events (Weingart et al. 2000).

4.3.1.4 Users' well-being jeopardize

The considerable amount of time that nurses must spend at a computer when working with the EHR brought out other issues that were not as pronounced before the implementation of the new technology. One such issue is the seating comfort, or more appropriately seating discomfort, caused by the high wooden backless stools (Figure 4.7b). Since having to use these stools, many nurses reported that they frequently suffered from back and shoulder pain that forced them to be absent from work. This unfortunately aggravates the nurse shortage problem already experienced in the local health region. Also, coupled with the heavy mouse manipulation necessary to navigate the deep hierarchical information system, conventional computer hardware posed added difficulty to right-handed people. Right-handed nurses frequently had to switch their dominant hand between a mouse and a pen while preparing for their shift (Figure 4.8a & b). This increased both preparation time and muscle fatigue.

Moreover, with the new technology, nurses no longer gathered inside the shift change room (Figure 4.4a). Instead, they spent most of their time during shift change at a computer reading medical reports of their patients. They either used a COW which was usually parked along the ward wings (Figure 4.9a) or a computer inside the computer room (Figure 4.9b) depending on its availability. When reading reports in a hallway, nurses were usually distributed making it almost impossible to socialize with their colleagues. While the COWs offered mobility, nurses actually felt more distant from their colleagues because they were all scattered over the ward wings and were usually too busy with the information system. Thus, they much more rarely found opportunities for social interaction. Even when they could gather inside the computer room, the set-up there did not support interaction, especially because they had to focus at the computer screen in front of them (Figure 4.8). Therefore, many nurses complained that they missed the rich social interaction that used to take place with their colleagues inside the shift change room (Figure 4.4a). Since using the COWs, a nurse commented, *"very often I felt so lonely, it's like… I'm the only one here… I don't like it…"*

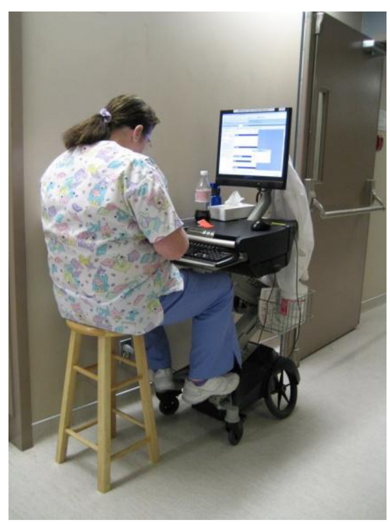
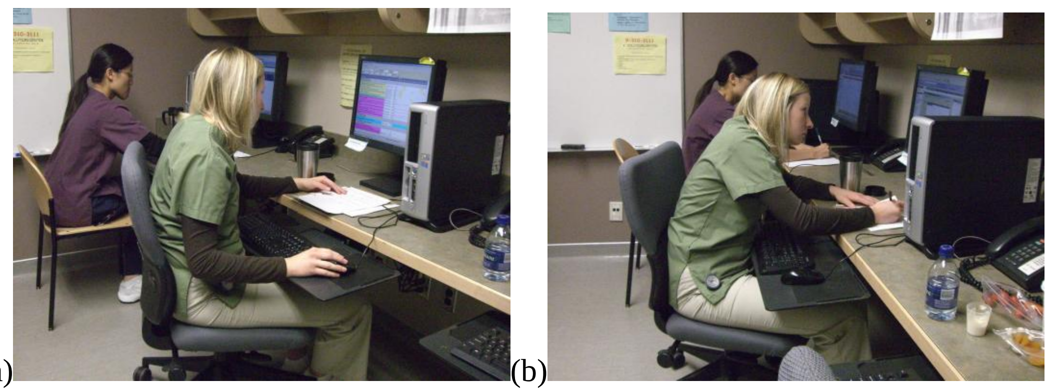
(a)  (b) 

Figure 4.7 (a) A typical setup when nurses prepared medications - a COW placed beside a med-cart (b) Nurse sitting on a stool when working at a COW

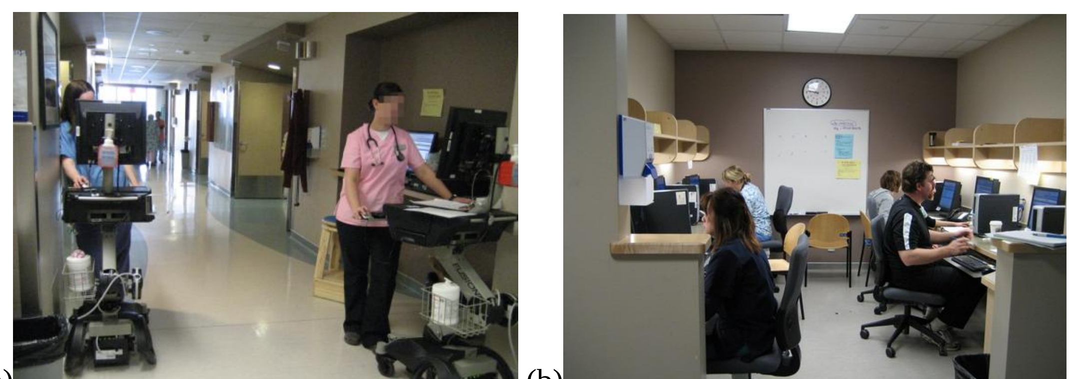
4.3.1.5 Continued use of paper personal notes

Although nurses were expected to directly interact with the COW for information access and entry at points of care without using intermediary artefacts, all nurses observed still prepared paper personal notes. They carried and used these worksheets during their shift as an immediate information source and an intermediary notepad, in the same way as before the COW was deployed. Most of them made adjustments to the layout of the note-sheet and extracted more information from the EHR to the personal notes to make up for the unavailability of frontline information provided by the phased-out patient care summaries. For example, the personal notes after the COW deployment in Figure 4.10b has an extra column for holding medication schedules and information on the right hand side (i.e. the column with 08 and 12 circled which referred to the times at which



(a) (b)

Figure 4.8 (a)(b) Nurses juggle her hand between writing and using mouse



(a) (b)

Figure 4.9 (a) Nurses focused on computer screen and are distributed along ward wings (b) Nurses preparing for their shift in the computer room

(a)

(b)

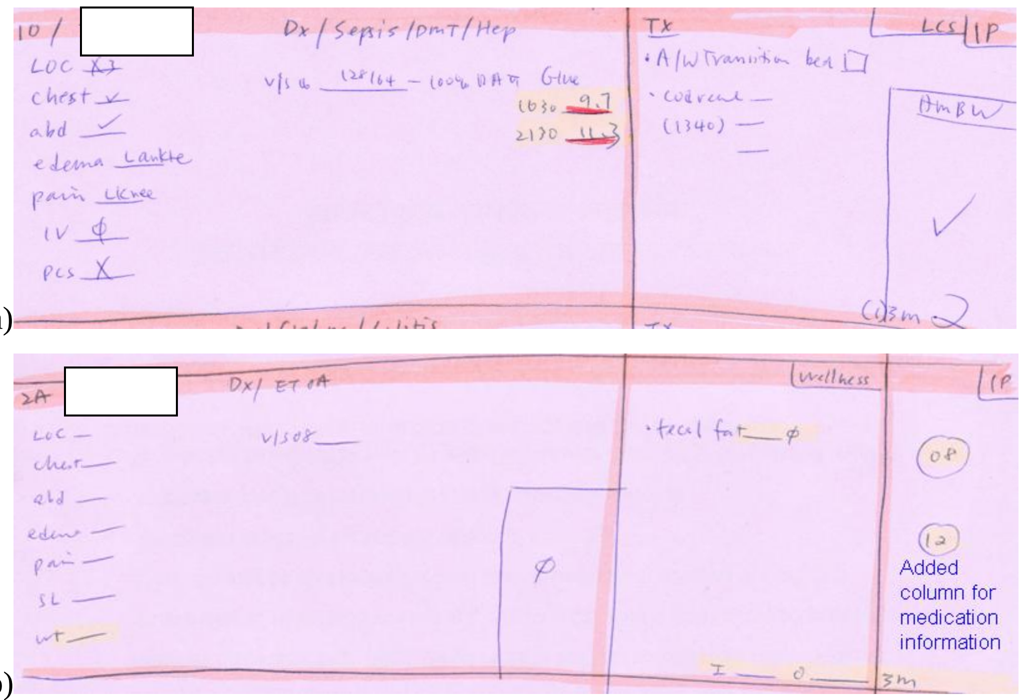


Figure 4.10 Simulated paper personal notes (a) before COW deployment with 2-column format (b) after COW deployment with adjustment in the layout and an additional column on the right for medication information - labelled in blue (patient names are masked)

medication was to be administered). The one before the COW deployment (Figure 4.10a) has only two columns since nurses had a separate medication list printed out hourly. In fact, they all commented that the COW could not replace their personal notes which provided them an important personal information space which they could customize for facilitating information retrieval and it was thus a crucial part of their work practice (Tang and Carpendale 2007b).

Despite all the difficulties confronted by the nurses in the early stage of the technology deployment, most of them were hopeful that the difficulties would subside over time.

4.3.2 Late Stage of Technology Deployment

Eleven months after the initial deployment of the technological set-up, I followed up with another observation to uncover longer-term phenomena. I observed improvements in some of the problems identified in the early stage, some problems that persisted or

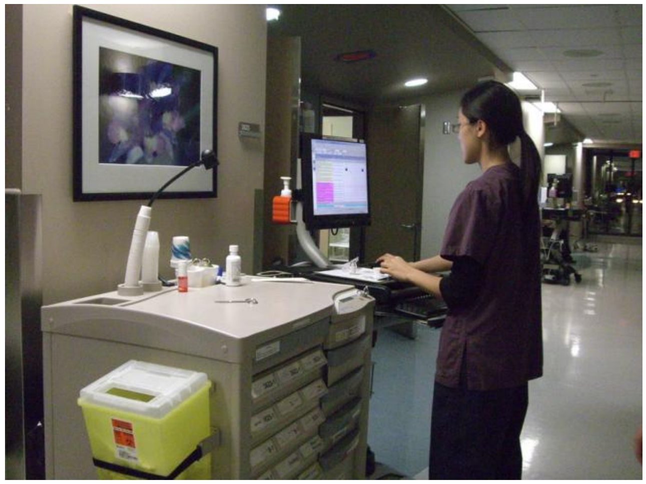


Figure 4.11 Moving the mouse to reinstate the timer for power-save mode while preparing medication

worsened through the adoption period, and some new problems that had emerged over the longer period of time.

4.3.2.1 Observed Improvements

Workarounds to improve quality of patient care

Nurses were found to adapt better with workarounds to the power-save log-off problem identified in the early stage of adoption. Some of the nurses would arbitrarily move the mouse when being alerted audibly in the last 10 seconds so that they could reinstate the timer for idleness (Figure 4.11). Thus the frequency that nurses were being signed off by the power save feature had been reduced. Nevertheless some nurses still found this distracting from their task-at-hand.

Regained time for patient care

Nurses have become more familiar with the new information system over time and use. Most problems that they encountered when retrieving or entering information in the early stage of adoption have been improved. They generally had better knowledge of where specific information resided and were also more familiar with the terminology in the system. Nurses told us that they were now faster at reading and charting with this system

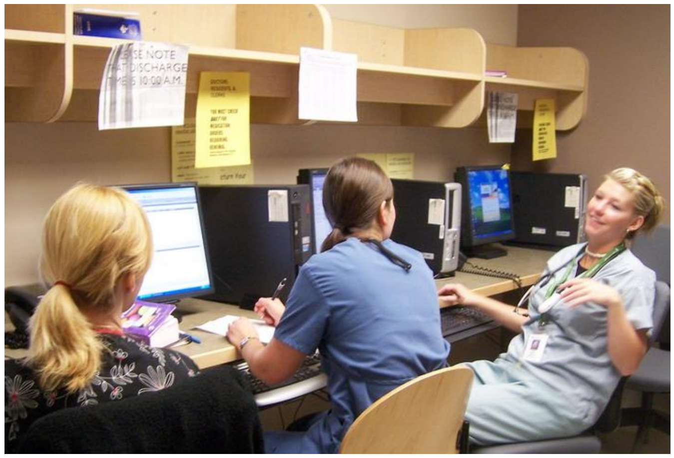


Figure 4.12 Nurses had to turn their body and to pause their task while socially interacting with their colleagues

and this speed-up was clearly noticeable in observations. Thus nurses, in comparison to the early stage observations, were now able to spend more time on delivering actual patient care.

Nurses actively combat deteriorating social interaction

Nurses were found to engage in social communication more frequently inside the computer room during night/day and evening/night shift changes. With the existing physical set-up, nurses had to turn their body around and also had to pause their task-at-hand in order to engage in conversations with nurses sitting on the opposite side of the room or with nurses sitting beside (Figure 4.12). Yet, as most nurses had realized the fading social interaction since the technology adoption, they therefore put in conscious effort to improve the communication among themselves.

4.3.2.2 Persistent or Worsened Problems

Increased Immobility

The COWs were intended for mobile use, however, more problems were identified that contributed to its failure to fulfill this anticipated use. These problems included unreliable network connectivity, suboptimal battery life, and unsatisfactory ergonomics.

First, the connectivity problem was attributed to either the wireless network being unstable or the presence of "dead zones" in scattered areas on the ward. Unstable wireless connection was often experienced while nurses were working on a COW. Sudden log-offs required nurses to re-log on and to tediously navigate to the last visited page in order to continue their task. Other times, when nurses moved a COW to use, e.g., in a patient room, connectivity might not be available. Some nurses would try to slightly shift the device back and forward or at another orientation in an attempt to get connectivity when they were not too time-pressured. Most nurses would just give in and resort to more reliable paper artefacts, specifically their personal notes for information and as a notepad.

Second, more batteries were reported as wearing down too quickly and the COWs were constantly required to be plugged in for recharging (Figure 4.6). A nurse responded in the questionnaire, *"I like to take the COW into patient room but they ALWAYS need to be plugged in if using them for any length of time longer than 5 minutes…"* Thus with such short battery life, either the task-at-hand got interrupted when the battery ran out or nurses would subconsciously, similar to the medication preparation reported in the early stage of deployment, rush through the task. The former would frustrate the nurses and impede the work flow whereas the latter might result in serious adverse consequence such as medical errors.

Third, the physical attributes of the COWs remained unchanged. Since the carts were bulky and clumsy, the COWs were counterintuitive as a mobile device. Figure 4.13 shows a crowded hallway where pushing a COW is no easy task especially when there were other people, structures or equipment present such as slow-moving patients or a janitor with a cleaning cart.

While five (out of 29) nurses said they almost never brought the COW into patient rooms, only one said she almost always brought it to patient rooms, except for isolated rooms. Most other nurses (23/29) either sometimes or occasionally brought the COW into patient rooms for varying reasons such as in the initial rounds of assessment, critical events (e.g., treating a dying patient), performing certain procedures (e.g., blood transfusion) and explaining complicated medications. Nurses also explained that they rarely brought the COW into patient rooms at night as its bright screen could disturb the patients' sleep.

Declining well-being

Nurses continued to complain about the back and shoulder pain problem caused by the inappropriate seats. Regardless, they still preferred sitting to standing for reading or charting the EHR. Many nurses expressed bitter comments towards the seating facilities, e.g., *"I refuse to stand or sit on stool, it hurts lower back, no back support with stools, also hard on feet…"*

4.3.2.3 Newly Emerged Problems

Weakening interpersonal communication

Many nurses found that the COWs impede communication with their patients because of its size and rigidity. The computer appeared less "human" and more intrusive during

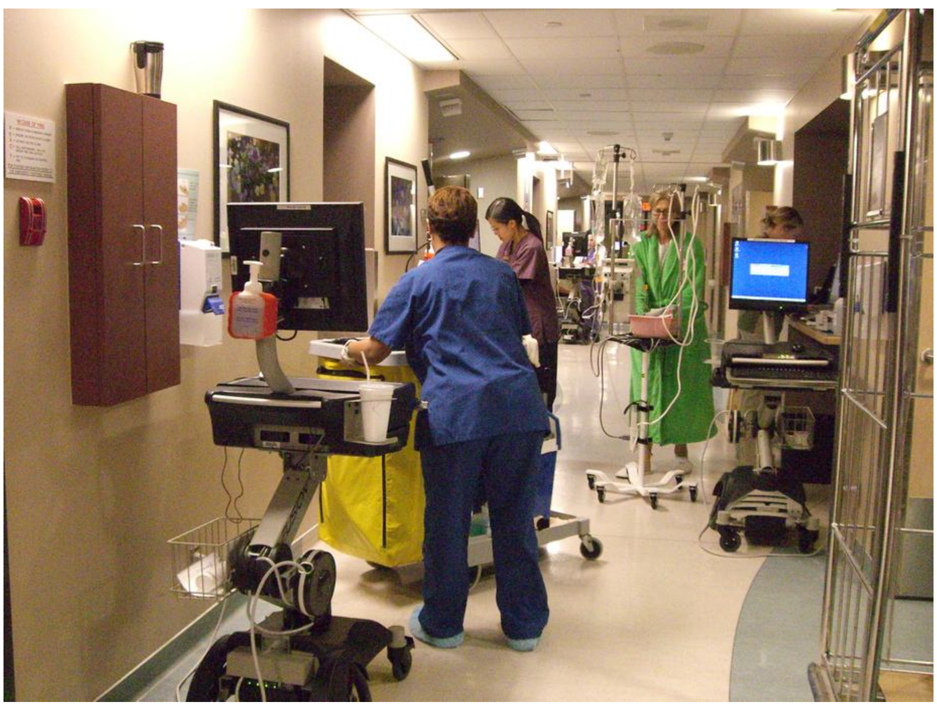


Figure 4.13 A crowded hallway parked with COWs making it difficult for patients to go through or janitors to carry out their work

interpersonal communications. Since information can only be entered in a constrained way at a computer, it is not as flexible as the paper medium which allows easy interweaving with the ongoing assessment and explanation of procedures and medication. COWs seemed to interfere with the delivery of comfort and sentimental work (as defined in Strauss et al. 1985) that are constantly required in medical settings.

Mechanical flaws

Nurses found the mobile carts difficult to steer around because of their sticky or misaligned wheels, similar to what many of us have experienced with “difficult” shopping carts in supermarkets. Some nurses also complained about the difficulty of adjusting the height of the monitor and keyboard as well as the mechanical stickiness of the keys. As a nurse’s job is always time-pressured, they resented having to deal with these technology-related obstacles.

Role-models not conforming to organizational goal

The technology deployment was planned for pioneering the ward towards paperless. However, it was observed that several mentoring sessions in which the mentors, who were usually experienced nurses, were teaching their “students” to prepare paper-based personal notes by extracting information from the EHR. This continuing use of paper-based artefacts as the communication tool for reporting and at meetings was observed with all the participants.

Frustrated adopters

With the problems described above, some of the nurses have become frustrated with the technology. Several nurses even explicitly said that they would avoid using the COWs whenever possible. An incident was encountered where a nurse was looking for a computer to read reports at the beginning of her shift. The nurse refused to use any of the COWs idling along the hallway. Rather, she walked around the ward to try to find a desktop computer. It was day/evening shift change so desktop computers were not available in the computer room. When a nursing aid suggested to her to use a COW, she simply snapped, *"No, they never work!"* She finally settled down at a desktop computer at the nursing station after checking all the ward wings for unoccupied desktops.

This study found that nurses had a strong preference for desktop computers over the COWs. 96% of the questionnaire respondents indicated that desktop computers were their most preferred device for reading and charting reports during shift changes. The primary reasons for the choices were based on the wired network stability and performance, as well as the seating comfort adherent with most of the desktop computers. Most nurses criticized the wireless connection as unstable and as causing different kinds of problems. These problems started from the sign-on process which often failed, or required several trials or sometimes required rebooting of the system. Then intermittent freezing and complete disconnection from the system was frequent in the course of working with the information system. Thus, most nurses were reluctant to work with the COW particularly when they needed to use a computer for a longer period of time such as when they read reports at the beginning of a shift or charted at the end of their shift. In addition, the wireless network was generally slow and sometimes unresponsive. Nurses complained that page loading was sometimes so slow that they had to halt the task at hand and only returned to retry when they had time later. In these respects, desktops offered more consistent performance and they were generally faster. Thus, nurses would always prefer desktops over the slow mobile COW, especially in view of the time pressure that nurses constantly face.

In the course of the data analysis, a considerable amount of negative feedback on the COW adoption was noted, mostly due to their unsatisfactory technical performance and their lack of consideration for human factors. I thought that the questionnaire respondents would not recommend deploying the same technology in other wards. However, surprisingly 15 of 28 respondents unconditionally recommended the use of the COWs in other hospital wards and six respondents conditionally recommended the technology. The conditions were all expected improvements to solve the problems described in this section. Only four were firm on not recommending the technology to other wards. I was intrigued by the questionnaire responses. Thus, I reviewed the raw data again and randomly interviewed some nurses. It was found that there were not enough computers prior to the deployment of the COWs. Nurses often had to wait for their turn to use a computer. Therefore, despite the flaws with the technology, they still opted for their adoption in other wards as they believed that the devices would add valuable resources to their colleagues working in other wards. The deeper connotation is that if it is decided that the COWs are to be removed, they will then lose these valuable computing resources now available to them. Therefore to the nurses, the COWs provided extra information devices regardless of the adjustments they may have to make in order to compensate for their flaws.

For the same reason, COWs were most preferred for preparing medication. Prior to adoption of the new technology, a medication list would be printed out for each nurse on an hourly basis to prepare medication at the med-cart and multiple nurses could work at a med-cart simultaneously. But medication information is now only available on screen with the new information system. As each ward wing was served by only one med-cart, it would be inconsiderate to bring the med-cart to a desktop computer to prepare medication. In such case, only one nurse could use the med-cart at any one time. With the COWs, multiple nurses could share a med-cart by placing their COWs beside it. Hence, this again showed that the COWs added valuable resources to the nurses.

4.4 Discussion

This study revealed an array of difficulties that nurses encountered either directly or indirectly from the deployment of the COW in our study ward. As a result, many of the participants either completely abandoned or tried to avoid using a COW. These study results can be used to either suggest changes for the COWs or point to new design directions.

4.4.1 Issues to Resolve with COW Use

As the COWs do offer valuable extra computing resources to nurses' shift work, it is important that the shortcomings identified be addressed. The technical and engineering problems associated with the mobile device require appropriate technical support team servicing. The batteries should be regularly tested and recharged to ensure that they function for a reasonable time period, e.g., 24 hours, without interruption and it seems reasonable that this not be considered to be part of a nurse's job. Faulty batteries should be replaced. Technical support servicing should also be in place to ensure reliable network connectivity throughout the deployment area. Thus, decreasing the observed problems with the COW deployment requires adequate funding for required technical support servicing.

The physical form of the device should be re-thought. New versions could be improved and the ergonomic factors that influencing nurses' experience with the device could be addressed. Currently, this includes the maintenance of various engineering parts such as the height adjustment, the wheel alignment and smoothness, as well as the sensitivity of the input keys.

The social concern experienced by the nurses also needs to be addressed as social interaction has been found to be crucial for collaborative work. A solution to resume social interaction during shift changes is to equip the shift change room with wired computers so that nurses can continue sitting around a large table to prepare for their shift while they casually communicating with each other.

Nevertheless, I am more interested to find out why most nurses stated that the mobile device cannot replace their paper personal notes in delivering nursing care. Even if assuming that the identified technical, engineering, and social problems engendered by the COW deployment can be addressed, it appears that there still will remain problems associated with the use of and advantages offered by paper based artefacts. From the studies (Tang and Carpendale 2007a, Tang and Carpendale 2007b, Tang and Carpendale 2008b), the construction of these paper artefacts was consistently observed. I interviewed nurses to find out when, where, and how these artefacts were used during their shift. By examining the paper artefacts that were collected at the beginning and at the end of their shifts allowed us to trace how these artefacts were used during their shifts. I also observed their use at reporting and handover.

4.4.2 Paper Personal Notes vs. COW

In this section, I compare observed functionality of paper based artefacts for mobile information access with the COW as a mobile information source. The paper artefacts are personally created so they display a high degree of personalization (see Tang and Carpendale 2007a for details). I also identified several important roles that these paper artefacts play in the nurses' actual work practices (see Tang and Carpendale 2008b). The paper artefact was used to:

- hold the work plan for delivering patient care,
- provide a bedside information source,
- be an opportune notepad for recording information, and
- be an information source for reporting and handover.

Table 4.1 A comparison of paper personal notes and the COW

Paper personal notes	Computer on wheels
Foldable and portable in pockets, so low cost	Wheeled cart for mobility, difficult to steer in crowded space
Customizable as work plan, overview visualization	Information scattered in different screens
Manual construction help build mental map	Memory overload of information
Convenient, low-cost bedside information source	High cost (i.e. heavy-weight) information access
Flexible, low-cost immediate notepad	High cost (i.e. heavy-weight) information entry
Centralized, overview information basis for reporting and handover	Information scattered in EHR or memory overload

Table 4.1 shows how these vital roles are realized with paper based artefacts (left-hand column) and with the COW (right hand column). Note the sharp difference between the flexibility and mobility provided by paper in contrast to how the COW has failed to live up to its intended use as a mobile and ubiquitous information artefact in nursing care.

4.4.2.1 Work Plan

Information recorded in the personal notes includes action items such as reminders and to-dos, alerts, prompts, scheduling, and verification information. The manner in which these information types is presented on the personal notes, is often customized through visual augmentations such as highlighting, annotations, special signs and icons, color coding and spatial layout. These visual augmentations inform a rich set of meanings in addition to plain medical facts. When nurses prepare their personal notes, they cognitively make plans for the temporal performance of the tasks that need to be done during their shift. Also, the manual writing of information on their personal notes helps them build a strong mental map of their patient's condition and their shift work. Thus the notes inform them of the tasks to be performed, the order in which the tasks should be carried out and an overview of their shift work.

In contrast, the COW does not offer the same affordances. As information displayed on a COW cannot be customized, nor can specific information be extracted and placed separately for personal use, nurses relying on the COW must memorize the information they read. Alternatively, they will have to frequently access information to make sure the tasks are carried out as required and in the correct temporal sequence. Therefore, the COW does not provide the work plan support for the nursing shift work.

4.4.2.2 Bedside Information Source

Paper personal notes are portable and malleable. They can be folded and put in a pocket or conveniently placed on a clipboard for easy writing, thus can provide customized information at points of care. The customized notes allow nurses to quickly look for specific information. Therefore the information access process is light-weight and can also be easily interwoven with other tasks or a conversation.

While the COW also allows information access at bedside, the cost of the process is high. Nurses have to log on to the system before they can navigate to the appropriate screen for required information through mouse manipulation. As nurses may have to look up information frequently during their shift work, this high cost of information access is likely substantial considering the constant time pressure that nurses face at work. Besides, with the physical barrier of the computer screen, keeping constant eye-contact with patients or maintaining a conversation while searching for information in a COW is no easy task. Similar finding was also reported in Newman and Cairns (2009) that doctors had difficulty in continuing conversations with their patients when they had to focus on their computer for more than five seconds.

4.4.2.3 Opportune Notepad

During nursing work, new data emerges frequently and ubiquitously especially for unstable patients. Nurses often first record the emerging information in their personal note as a means to reduce their mental workload and eventually report it in official documents of varying media. Personal notes are generally pre-structured at its point in time. Nurses thus can quickly scribble new but anticipated data in specific information holders on their personal notes, while they can also casually add the new and unanticipated information in available open space not specified in the usual spatial layout of their personal note. Thus the personal notes allow nurses to flexibly and speedily scribble notes and annotations as a temporary repository.

On the other hand, nurses cannot use the COW in the same way to quickly or easily scribble down newly emerged information. Nurses either have to rely on their mental capacity or first access the information system and then type in the new information using a COW at points of care. The former easily overloads the nurses’ memory and it also runs the risk of them forgetting information that is important in the patient care. The latter is problematic due to the high cost of information entry. It undoubtedly further strains the time-pressured nursing work.

4.4.2.4 Information Basis for Reporting and Handover

New information added to the personal notes during a shift often forms part of a patient's illness trajectory. Therefore, such information must be properly documented for use by other clinicians and for later review when needed. Nurses are required to report their work at the end of a shift, to the succeeding nurse and to the charge nurse. Their personal notes, containing the newly emerged information which also represents the patient's shift-specific illness trajectory, thus serve as important information basis for reporting.

Using a COW to display information during reporting can be a challenge as information is scattered in the hierarchical information system. Nurses either have to navigate, at high costs, to different screens for finding the right information to report or rely on their memory which again may result in reporting or handover of incorrect information due to memory lapses. Focusing on the computer screen also makes it difficult to keep eye contact with their colleagues.

4.5 Design Suggestions

I discussed the COW's failure to replace the paper personal notes in nurses' shift work in the study ward. I suggest that paper will continue to play an integral part in nurses' work practices due to its unique affordances. Thus a potential future technology design could focus on how the paper and the digital world may be bridged so that information can be converted efficiently between the divide. I thus propose that the system should:

- allow easy transposing of information from multimedia sources to a paper-like physical artefact,
- allow portable, flexible and low-cost use of a paper-like artefact to support and enhance work performance, and
- allow moving information from the paper-like artefact back to the multimedia sources with minimal effort to provide timely, low-cost and continuous information flow.

4.6 Chapter Summary

This chapter presented an observational study conducted at two different time frames to investigate the short-term and long-term impact of a mobile technology deployed in our research ward on nurses work practices. With the knowledge of the basic dynamics and practices of nurses' information flow gained from the previous chapter, I identified the impacts of the deployment of mobile computers-on-wheels on the nurses' information flow. They included problems in technical, engineering, organizational and social issues. While I proposed solutions to address these identified problems to improve the use of the computers-on-wheels as they were found to be valuable additional computing resources, I pointed out the mismatch between the deployed mobile technology and the nurses' current work practices in the study ward to draw attention to the importance of providing technology for supporting rather than impeding work. To do that, I compared the COW to the paper personal notes in terms of the latter's important roles as work plan, bedside information access, opportune notepad and information basis for reporting in supporting nursing practices. I then proposed to design technology to bridge the paper and digital media to support the shift work. The proposed technology is later prototyped and will be described in Chapter 7 and 8. In the next chapter, I will present a framework for nurses' information flow that I developed from the findings of the first observational study presented in Chapter 3 and a distilment of previous relevant literature.

Chapter 5. A Framework for Information Flow during Nurses' Shift Change

The last chapter presented an investigation into how the deployment of a mobile technology impact nurses' information flow and work practices, which pointed to the importance of designing technology to support rather than impede nurses' work practices. We also contrasted the affordances offered by paper personal notes against that provided by the deployed mobile technology. The study revealed that designing technology to bridge these media could be beneficial to support nurses' work practices while facilitating the information flow. Moreover, the literature review presented in Chapter 2, together with the field study presented in Chapter 3 provided considerable insight into the processes and challenges for effective shift change. However, from the perspective of designing technology to support shift changes, it would be helpful if the knowledge generated by these studies could be formulated into an effective framework. Such a framework has the potential to integrate current knowledge to provide a coherent description, to be useful as a tool which can aid in assessing current technology use, and might prove useful in informing the design of new technologies. For example, such frameworks have been shown to be effective as assessment tools, as in Nielsen's (1994) usability heuristics and Gutwin and Greenberg's (1999) Awareness Framework.

Other frameworks have also been developed for investigating shift changes in a variety of work domains. Grusenmeyer (1995) presented a framework to study shift change in a paper mill plant. She differentiated four phases during shift change: the end of the shift, the arrival of the incoming operator, the meeting of the operators and the taking up of post by the incoming operator. Although her framework was derived from observing dyadic shift change among operators in an industrial context, her framework helps guide the general study of shift change across settings, because the phases she identified exist universally.

Subsequently, Behara et al. (2005) proposed a conceptual framework for studying shift change in emergency rooms. This framework addresses four attributes of a shift change: the type of process in which it occurs (e.g., degree of standardization, production volume level and nature of the process), the primary content, the structural issues (e.g., nature of participants) and the dynamic issues (e.g., degree of structuredness and degree of interactions required). It can be used to understand the fundamental properties of a shift change and to categorize and compare different shift changes for redesigning the work processes.

Patterson et al. (2004) identified 21 strategies for shift handoff from studying four settings: a space shuttle mission control, two nuclear power generation plants, a railroad dispatch center, and an ambulance dispatch center, with high consequences for failure. These strategies aimed to provide for effective coordination and communication during face-to-face verbal shift handoffs and have since been widely cited in studies on shift change. Although these strategies were developed from shift change studies in various settings, most of the strategies appear to be most applicable to shift change in space shuttle mission control environments as the data collected in the other settings were not originally collected for this purpose.

My proposed framework addresses six important factors of information flow during shift change in medical settings and allows researchers to flexibly re-configure the factors for studying the information flow and identifying areas for improvements and, thus, is designed to be more comprehensive and pragmatic.

I first present the framework by drawing evidence from our own study and previous literature. Then, I discuss the framework in the context of information flow and technology design.

5.1 The InfoFlow Framework

The InfoFlow Framework has six factors: information, personnel, artefacts, spatiality, temporality, and communication mode. These factors are not stand-alone elements independently contributing to the information flow process but are highly interrelated (Figure 5.1). All of these factors impact upon and are impacted by all the other factors. For example, the kind of information artefacts used influences the timeliness with which information is communicated among clinicians. In addition to their importance in our own studies, the importance of each of these factors has been reported in other studies conducted across various domain settings (e.g., Bardram and Bossen 2005a, Bardram and Bossen 2005b, Forsythe et al. 1992, Harrison and Dourish 1996, Luff and Heath 1998, Reddy et al. 2006).

The remainder of this section describes each factor of the framework in detail. Though it is possible to describe this framework starting from any one of the factors, I start from the information factor, at least in part, because effective transfer of information has so frequently been noted as the primary objective during shift change (Kerr 2002,

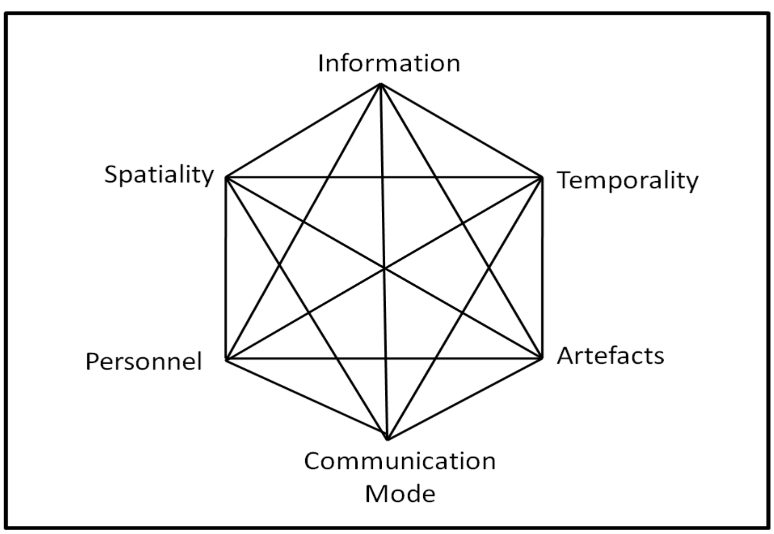


Figure 5.1 A framework for information flow during shift change consisting of six interrelated factors

Lardner 1996, Sexton et al. 2004, Wilson et al. 2005). The framework discussion then moves to personnel and artefacts, describing the relationships between these factors. Lastly, the spatiality, temporality and communication mode of the shift change process are discussed in association with the previous factors. I will draw on our own study and experiences reported in the literature to illustrate the roles played by the factors in shift changes. While each of these individual factors justifies focused research, my framework's contribution is to provide a holistic view of the shift change process so that it can be studied in a systematic manner using existing knowledge and concepts to investigate the complex shift change processes.

5.1.1 Information

Information is the essence of communication and central to all collaborative work. In fact, medical work is regarded as information work as information is key to task accomplishment when delivering patient care (Strauss et al. 1985). Communication of task-pertinent information across shifts has also been repeatedly found to be essential to the operation continuity regardless of the complexity of the shift change process (Grusenmeyer 1995, Lardner 1996, Wilson et al. 2005). Hence, information communicated during shift change directly influences the quality of healthcare. For our purposes, information includes facts, knowledge, assessment, instructions, graphical representations, perceptions and meanings received and interpreted.

During shift change, two kinds of information are often communicated: work-related and interpersonal information. Although interpersonal information is important for group cohesiveness and team morale, this framework primarily addresses the communication of work-related information. The work-related information in this case is typically patient-specific and is thus uniquely defined for each patient's illness trajectory, such information is important to plan nursing care for individual patients and temporally coordinate the care plans for multiple patients. Thus, the assumption is that efficient and effective information flow during shift change facilitates the continuity of patient care, which will in turn lead to reduced occurrences of adverse events contributed to or caused by communication errors during shift change.

A number of documented adverse events that have taken place in medical settings have resulted from or were contributed to, by miscommunication between the incoming and the outgoing nurses during shift change. For example, the case of the amputation of a patient's wrong leg took place because the outgoing nurse did not inform the incoming nurse during shift change about a clerical error that the incorrect leg to be amputated was made on the surgery schedule (Patterson et al. 2005). Such an unfortunate event could have been prevented if a standard set of information to be communicated was enforced during the handover. Thus, many studies, including my baseline observational study, attempted to identify a set of information that must be communicated during shift change.

Without standard guidelines as to what information must be communicated, the informational contents were found to exhibit a high degree of variability in both quality and quantity. For example, Currie (2002) identified patient's admission diagnosis, treatment received, demographics, present restrictions, care plan and medical history being the most important types of information for discussion during shift change. Baldwin and McGinnis (1994) listed a set of specific information that is crucial in shift reports: vital signs, activity, diet, labs, tests, IVs, etc. In general, previous studies found that information required for the patient care continuity varies across settings. For example, an acute oncology ward emphasizes the treatment plan and the patient's illness trajectory while a general medical ward where patients are less seriously ill may find social support available to the patients a crucial piece of information. Therefore, the set of information required for shift change should also reflect the nature of care in the particular setting. Thus, instead of making another list of specific information content, I proposed several categories of information in terms of their roles played in the nursing work. They are reminders and to-dos, alerts, prompts, scheduling and reporting information (Tang and Carpendale 2007). These functional information types are typically action-oriented and so can help nurses build a mental model of their work plan while they are acquiring information for their shift.

While a pre-determined set of information helps ensure that necessary information is communicated, it is difficult to know if incorrect information has been communicated or incidental information has been missing. Unfortunately, the identification of such incorrect or missing information is often a result of hindsight investigation to adverse events. Nevertheless, a standardized protocol on the information set should help improve the quality of information flow during shift change.

Given a specific set of information, the next question is where the information can be found. Information does not exist in a vacuum; instead, it typically resides in a person's head or is inscribed in an artefact.

5.1.2 Personnel

With increasing specialization in medicine, multidisciplinary care is now common such that clinicians all carry information specific to their work duties and their expertise (Gulmans et al. 2007, Gurses and Xiao 2006, Kane and Luz 2006). It is therefore important to identify the people who carry and/or require information that is necessary for the continuity of patient care across shifts, as well as the kind of information they each carry/need. I regard these personnel as *information participants*.

Information participants in a typical nursing shift change are nurses of the same discipline. But it may also include nursing aids, the charge nurse, specialty nurses (e.g., a prick nurse), unit clerks, physicians of different specialties (e.g., general practitioners, cardiologists, and surgeons), or ancillary professionals (e.g., physiotherapists, social workers, occupational therapists and laboratory technicians), largely depending on the patients' needs.

In our study ward, patients' treatment and care plans are updated frequently due to its acute care and teaching nature. Thus, physicians are occasionally seen to instruct incoming nurses or to confirm their understanding for carrying out the most current treatment and care plan during shift change. In the meantime, as information is often entangled with the context of its production, incoming nurses would actively connect with relevant clinicians for interpretation and clarification, if necessary, of the information they acquired (Berg and Goorman 1999). In this regard, clinicians' credibility could influence the integrity of their information, and thus may impact the flow of information when (re)verification of information is deemed necessary (Berg and Goorman 1999, Cicourel 1990).

Questions and clarifications are generally encouraged at shift change to ensure that correct information is being understood across shifts. However, Manias and Street (2000) reported that hostility and competition may also be present at shift change and that if this is the case, it is likely to hamper team morale. Junior nurses may also be too intimidated to ask questions making them unable to fully understand the current operation. Thus, it is likely beneficial to be able to identify such vulnerability in the information flow for improvement.

5.1.3 Artefacts

Artefacts are extensively used to coordinate collaborative work (Bardram and Bossen 2005a, Xiao 2005) and as organizational memory (Gurses et al. 2006). In the medical setting, a wide range of information artefacts are used to coordinate the delivery of patient care. Examples include large whiteboards, patient charts, work schedules, desktop computers, personal digital assistants and disposable note sheets. These information artefacts possess varying characteristics in their form factors, interactivity, mobility, and life span contributing to their affordances for specific roles and functions played in the collaborative work. For instance, the patient charts in our study ward, which are a big binder of paper documents containing multidisciplinary information, often contain printed documents, annotations and drawings specific to a patient's condition such as a sketch of his/her wound and its approximate location.

An artefact's material characteristics also impact the type of information that it may carry (Bardram and Bossen 2005a) whereas some artefacts are designated for use by specific personnel only. Therefore, rarely would one single artefact carry all the information necessary for a patient's diagnosis, treatment and care. In practice, information is to be accumulated from multiple artefacts. Although information may be overlapping in the artefacts, certain level of data redundancy has been found to be beneficial in reducing the risk of erroneous communication which can in turn help forestall adverse events (Cabitza et al. 2005, Lardner 1996).

In fact, reviewing documentation in various forms of artefacts can help incoming nurses to understand the tasks that have been performed, the current status, and likely a projection of future plans (Patterson and Woods 2001) and thus will be useful for the continuity of the operation. In our study ward, such shared artefacts are the large whiteboards containing shift-specific nursing care information, as well as the electronic health record (EHR) and the patient charts containing high-level multidisciplinary treatment and care information. Together, they provide a rich set of past, current and future plans and a trajectory for continuing patient care. Similar activities can be seen in other settings such as with incoming flight controllers, who also assemble information from a variety of artefacts offering descriptions for different aspects of the operation (Durso et al. 2007, Patterson and Woods 2001). This practice of gathering information from a variety of complementary information artefacts is also a recommended strategy for effective shift change (Patterson et al. 2004).

Organizational protocols and culture may also determine the kind of information an artefact contains and who has access to the artefact. Some artefacts are kept permanently as official and legal documents. Others may only exist ephemerally for mediating the work process and will be disposed afterwards. Of special interest, personal notes have been found to be pervasively used by individual clinicians and play a vital role in coordinating medical work (Hardey et al. 2000, Sexton et al. 2004, Tang and Carpendale 2007). They are often used to bridge the distributed information sources by providing information at points of care.

5.1.4 Spatiality

As medical settings are comprised of a collection of spatially distributed “work centers” (e.g., operating rooms, emergency department, ICU), personnel (e.g., patients, clinicians, non-clinical staff), and artefacts (e.g., clinical equipments and information documents), mobility is thus indispensable for accomplishing work. Bardram and Bossen (2005b) regarded medical work as *mobility work* because mobility is often required to bring together "the right configuration of people, resources, knowledge and place in order to carry out tasks." Mobility itself does not usually accomplish any concrete tasks. But without mobility, many tasks cannot be fulfilled. For instance in another setting, workers had to be constantly moving around in the waste water plant in order to gather the constantly-changing and location-dependent information for assessing the quality of the water treatment; a mobility practice has been referred to as "zooming with the feet" (Bertelsen and Bodker 2001). Similarly in the medical setting, mobility is not only necessary for achieving work during actual patient care, but is also vital during shift change for accessing distributed information participants and artefacts.

Nowadays, many medical organizations are replacing their physical records with electronic health records for remote information access and entry. This switch drastically changes the notion of information availability such that mobility does not always constitute part of the information seeking and retrieval process. Nevertheless, most organizations still retain a certain amount of physical documentation so that certain collaborative work is mediated through physical artefacts that are not linked to a computer system (Xiao et al. 2007). Hence, mobility is often necessary to access these physical artefacts.

To study information flow, this framework focuses on four aspects of spatiality. First, it is necessary to first locate *where* the required information is. This entails the need to find out the locations of pertinent information participants and information artefacts. However, as clinicians are always on their feet, locating them is a challenge. Fortunately, with the use of technology-mediated communication systems such as traditional paging systems or more advanced ubiquitous communication systems, clinicians can now be more easily located. Without these communication tools, locating a clinician can be time-consuming and frustrating.

In practice, information is often located in places where they are needed the most (Harrison and Dourish 1996). As such, the placement of an artefact often determines who has access to it (Xiao et al. 2007). For example, patient charts in our study ward are located in the central nursing station where clinicians always meet to discuss the “cases” and the patient charts are therefore at their fingertips. Also in the space shuttle control room, all relevant artefacts such as flight logs, radar display and flight strips are in close proximity to the specific flight controllers conducting the shift change so that information necessary for shift change is readily available. However, when shared artefacts are removed from their designated location, extra effort such as further mobility is thus necessary to locate them (Bardram and Bossen 2003). In our own study, we have observed many incidences where nurses had to spatially move around the ward to look for patient charts that had been removed from the designated cabinet.

Second, the spatial *distance* that must be made in order to access information should be evaluated. In this regard, knowing where relevant personnel and information artefacts are can help minimize the spatial distance that one has to cover when acquiring or handing over information.

Third, the *setup* of information centers impacts how effective information flow takes place and whether it supports social interaction. For example, the shift change room in our study ward, equipped with whiteboards for shift reports and a large table where nurses could sit together during shift change, provided an inviting environment for incoming nurses to prepare for their shift work. Conversely, when shift change takes place in public hallways, nurses are often interrupted by patients and their family, as observed in our study ward as well as from the literature (Meibner et al. 2007, Reason 2000). Such distractions are detrimental to the quality of information flow (Patterson et al. 2004). Besides, since nursing work is constantly intense and time-pressured, nurses rarely find time to socially interact with their colleagues during their shift. Thus many nurses value the opportunity for casual communication during the brief duration of shift change, as was evident in our studies (Tang and Carpendale 2007a, 2008a).

Fourth, the *information organization* on the artefacts also plays a role in the efficiency of information flow. To enhance information sharing, the organization of information in an artefact should also be studied. A well-structured template offering clear organization of information can facilitate information retrieval. Conversely, shared artefacts that do not follow an agreed-upon structure may render it difficult to retrieve information. Patient charts in our study ward used color-coded pages for different clinical disciplines. But sometimes clinicians do not follow the convention, making it difficult to seek required information. In fact, a familiar layout of information has shown to facilitate information retrieval which is especially valuable in time-critical situations, e.g., to rescue a coding patient (Hardey et al. 2000, Tang and Carpendale 2007a).

5.1.5 Temporality

Timely information is crucial for making a diagnosis, treatment and care plan. The progression of a patient's disease over time, together with the actions taken by people across different places, constitutes a patient's illness trajectory (Bardram 2000, Reddy et al. 2006, Strauss et al. 1985). This trajectory information is particularly important to nurses who are assigned with patients on a shift basis. They must find out the patient's medical history and illness trajectory in order to be able to perform appropriate patient care. Nurses must also take into consideration both the patient's temporal trajectory and their own time plan so that patient care can be delivered in a timely and efficient manner (Reddy et al. 2006).

To do this, nurses often mentally plan and schedule their work during shift change, based on the temporal constraints and flexibility of their patients as well as their own. They make schedules to minimize temporal ambiguity by arranging tasks in proper temporal order, synchronizing tasks for conflicting temporal activities and allocating temporal resources to overcome the problem of scarcity (McGrath 1990). In practice, however, scheduling and re-scheduling takes place constantly in medical work due to unexpected changes in patients' illness.

Shift change occurs in the overlapping period across consecutive shifts. Time assigned for the process varies in settings. But shift change is often time-consuming resulting in excessive overtime and inability to meet patient's needs during the process (McKenna 1997). Nurses' shift change takes 10 to 61 minutes to complete, depending on settings (Lamond 2000, Sexton et al. 2004, Tang and Carpendale 2007a) and costs about £1.5 million per year in UK (Hewitt 1997). Therefore the assigned and the actual time taken for shift change should be evaluated in order to achieve a healthy balance between the quality of information flow and the cost.

Clinicians work in different shift cycles, making them temporally separated. Therefore artefacts that allow them to asynchronously communicate with their collaborators are widely used. Patient charts are a typical example of such artefacts used to coordinate the collaborative work among multidisciplinary clinicians. These charts provide incoming nurses up-to-date treatment plan and progress report inscribed by other clinicians (e.g., physicians) so that they can carry out appropriate nursing care. In some settings, these coordinating artefacts not only provide a means for asynchronous communication between collaborators, they also serve as a permanent record for later review when needed, e.g., in a legal investigation.

The sequence of information access is sometimes important for achieving the best outcome of the information flow. The study of the space shuttle mission control shift change revealed that incoming flight controllers must first gather information from the data screens, flight log and other documentation before being updated by the outgoing controller. In this order, they were then able to build a good mental model of the current status which also helped them formulate their questions in the verbal handover (Patterson and Woods 2001). Similarly, Grusenmeyer (1995) found that if the incoming operator met with the outgoing operator before familiarizing himself with the operation activities from inspecting the machinery and the written documents, then the verbal exchanges would favour more to the information the outgoing operator considers necessary to hand over than the needs of the incoming operator.

Information flow activities may also exhibit some characteristic patterns at a collective level - temporal rhythms - that potentially allow others to orient and coordinate their activities for accomplishing tasks (Reddy and Dourish 2002, Zerubavel 1979). For example, incoming nurses in our study ward often started inside the shift change room to acquire information necessary for their upcoming shift and we have observed a nursing administrator taking advantage of this knowledge to move into face-to-face communication with all the incoming nurses simultaneously so that she did not have to look for individual nurses in their ward wings once their shift started. In addition, individual clinicians may also exhibit specific temporal patterns of information seeking activities during shift change that may be useful for other people to more easily locate them (Reddy and Dourish 2002, Reddy et al. 2006).

5.1.6 Communication Mode

Effective information flow is achieved through the coordination of spatial and temporal contexts of the work settings to allow information flows through specific personnel and artefacts in a timely and effective manner. Thus workgroups use a variety of communication modes to facilitate group interactions and collaborations (Orlikowski and Yates 1998).

Face-to-face communication undoubtedly offers the best quality of communication (Kraut et al. 1988, Orlikowski and Yates 1998). Yet, the mobile and dynamic nature of medical work often makes it difficult for collaborators to interact in this rich medium. Instead, technologies are often deployed to bridge the spatial and/or temporal separation. Despite being simplistic, the traditional same/different time/place computer-supported cooperative work (CSCW) model (Johansen 1988) provides an easy way to understand how technologies may be used to connect collaborators across time and place. In fact, the inherent characteristics of various technologies afford different mode of communication for accomplishing work tasks (as illustrated in Figure 3.18, top row). Paper artefacts placed in designated locations are generously used to mediate communication between temporally distributed collaborators through textual and free form annotations. Similarly, an open voice link allowed the space shuttle mission controllers who were spatially-distributed to listen to the updates and make corrections as necessary through discussions and negotiation as a team (Patterson and Woods 2001).

The increasing digitization of medical information also changes the way information is entered and retrieved. With a networked system, information is accessible remotely in real time allowing spatially and temporally distributed collaborators to communicate asynchronously. The concern here is how data synchronization with artefacts outside the network, typically paper documents, can be maintained.

Information's life span is tightly coupled with the mode used for communication. For instance, verbal communication is ephemeral unless it is audio-taped for future use. Information inscribed in official artefacts, both physical and digital, tends to be kept as permanent records. Therefore, a mismatch between them could lead to serious consequences such as when permanent record is not kept properly for accountability purposes in situations such as legal proceedings.

In the medical setting, information confidentiality is of paramount concern such that patient's personal information is strictly bound by ethical and organizational guidelines on how and where such information should be communicated and recorded, as well as who has access to the information. Thus an appropriate communication mode should be chosen for specific kinds of information.

On the other hand, Behara et al. (2005) found that the choice of communication modes plays an important role in the co-construction of a mental model for the operation during shift change. Yet, McKenna (1997) did not find any particular communication mode superior than the others. Instead, the appropriateness of a particular shift change style depends on the information required, the people involved and the artefacts available, as well as their spatial and temporal aspects.

5.2 An Example Guide for Using the InfoFlow Framework

In the previous section, I discussed each of the InfoFlow Framework factors, explaining their importance and describing the interplay between them. Here I concisely summarize

Table 5.1 A proposed question set for information flow during nurses' shift change

INFORMATION
What information is important for the continuity of patient care? • How many different kinds of information? • How does each kind contribute to patient care? • Is the set of information specific to the nature of care? • Is there a way to know if and what information may be missing?
PERSONNEL
Who has what information for the shift change? • Who are the information participants? • Who is/are the outgoing nurse(s)? • What information is required of each participant? • Who will be handing over the information? • What expertise, authority or credibility do the people have? • How do their position, authority and credibility influence the information flow? • How do individual's customization practices influence information flow? • Is the shift change an opportunity for social interaction? • How can interpersonal communication be supported? • Is the shift change an opportunity for educational purpose? • Do the participants collaborate or compete at shift change?
ARTEFACT
Which artefact has what information for the shift change? • Which are the information artefacts? • What information is carried by each artefact? • Who uses the artefacts for information flow? • Are the artefacts shared by multiple information participants? • Do the artefacts carry public or private information? • Do the artefacts carry permanent or ephemeral information? • How do the artefacts' form factor and material characteristics influence their role in the information flow? • Do the artefacts carry complementary or overlapping information?
SPATIALITY
Where is the information (i.e. the information participants and artefacts) for shift change? • Which artefact carries what information in each place? • Who carries what information in each place? • What information is present in each place? • Are the participants stationary or mobile? • Where are the information participants and the information artefacts? • How to locate the participants? • Are the artefacts stationary or mobile?

• How does their mobility/portability influence information flow? • How to locate the artefacts? • What characterizes each place? • How much mobility is necessary to access the places? • Does the place (including its setup) support information flow? • How do information in different places relate? Are the artefacts designed with a spatial template of information to support the information flow?
TEMPORALITY
When is the information (i.e. the participants and artefacts) available for shift change? • What are the participants' shift cycles? • How long is shift change officially? • How long does shift change actually last? • Does the information need to be acquired in a specific order? • How timely information is available? • Does the information require immediate attention? • Are the participants available for shift change at specific times only? • Are the artefacts available at specific times only? • Are the places for shift change only available at specific times? • Do and how different shift changes (e.g., day/evening and evening/night) vary? • What is the temporal characteristic of the information communicated during shift changes: out-dated, current or for future use? • Does the shift change process exhibit individual or collective temporal patterns? • Are shift changes temporally flexible?
COMMUNICATION MODE
How information is communicated? • What choices of communication are available? • How shift change is conducted? • What are the strengths and weaknesses of the method(s)? • What information is communicated via the method(s)? • Who uses the communication mode(s)? • Is there a preferred communication mode by individual participant? • Does the participants' expertise, authority or credibility influence the choice of communication mode? • What artefacts are used for the communication mode(s)? • Is the communication mode spatially constraint or spatially flexible? • Is the communication mode temporally constraint or temporally flexible?

these six framework factors into a chart (Table 5.1), in which a fundamental question for each framework factor is posed. From this question, sub-questions arise. By posing and answering these questions in a given situation, a relatively complete information flow shift change description can be generated.

In general frameworks are deemed useful if they can be informative in providing full descriptions, be useful in assessing and analyzing similar situations, and/or be helpful in generating new directions (Shields and Tajalli 2006). My InfoFlow Framework arose as a descriptive aid during the analysis of our field study data. Integration with existing literature further confirmed and strengthened it. Table 5.1 is designed to increase the usability of this InfoFlow Framework to better allow researchers to flexibly re-configure the factors for studying the information flow and identifying areas for improvements in their specific setting. However, I do note that while these factors are useful for characterizing the information flow process during shift change, they are not exhaustive. Other factors such as organizational mandate and social structure may also impact the information flow.

5.3 InfoFlow Framework and Healthcare Quality

In this section, I outline the medical 'Quality of Care' objectives and then discuss how my InfoFlow Framework relates to these objectives. The health care domain has become increasingly complex such that there are ever "more to know, more to do, more to manage, more to watch, and more people involved" than before (Institute of Medicine 2001). Thus the Institute has identified six specific Quality of Care objectives for improvement to achieve a high quality health care system:

- *safe* by "avoiding injuries to patients from the care that is intended to help them",
- *effective* by "providing services based on scientific knowledge to all who could benefit, and refraining from providing services to those not likely to benefit",
- *patient-centred* by "providing care that is respective and responsive to individual patient preferences, needs, and values, and ensuring that patient values guide all clinical decisions",

- *timely* by “reducing waits and sometimes harmful delays for both those who receive and those who give care”,
- *efficient* by “avoiding waste, including waste of equipment, supplies, ideas, and energy”, and
- *equitable* by “providing care that does not vary in quality because of personal characteristics such as gender, ethnicity, geographic location, and socio-economic status”.

Health care systems that achieve major gains in these six areas are expected to be better-equipped to meet the ever-increasing needs of patients. The application of health information technology has been shown to improve aspects of safety and efficiency (Chaudhry et al. 2006). Several barriers, mainly financial but also including resistance to utilization, limit its adoption in the hospital setting (Jha et al. 2009). Other barriers include the lack of information for decision makers on the effects or benefits of Health Information Technology (HIT) to workflow (Chaudhry et al. 2006). Arguments have been made that to optimize HIT utilization and adoption an iterative developmental-evaluative socio-technical and qualitative approach that recognizes the interrelationships between the practices of skilled providers and technology is required (Berg 1999). To help achieve these goals, the InfoFlow Framework can be used to inform the investigation of information flow in medical settings for improving safety, timeliness and their related workflow and technology utilization aspects.

Patient safety is a relatively new healthcare discipline which became prevalent in the 1990s when the frequency and magnitude of preventable adverse events was widely documented. The World Health Organization also regards patient safety an endemic concern after recognizing that healthcare errors impact 10% of the patients in developed nations around the world (Bates et al. 2009). Therefore, initiatives for improving patient safety have since been established and revised periodically to maintain the momentum towards improving patient safety through reporting, analysis, and prevention of medical errors that often lead to adverse healthcare events (Wikipedia – patient safety).

Meanwhile, the Joint Commission (formerly the Joint Commission on Accreditation of Healthcare Organizations) reported that inadequate communication between health care providers, or between providers and the patient and family members, has been found to be the root cause of over half of the serious adverse events in accredited hospitals (JACHO 2007b). In fact, failure to achieve the right configuration of people, knowledge, and resources in the right place and at the right time (Bardram and Bossen 2003, Bardram and Bossen 2005b) could lead to significant, perhaps detrimental, consequences. For example, a delay in treatment could result in a patient's irreversible worsening of his/her condition or even death. On a broader level, a delay in reporting a commutable disease could result in a pandemic; the consequence of which could be catastrophic such as a high number of fatalities. Therefore, *timely information flow* is crucial for quality patient care as it helps reduce the occurrence of dire consequences due to waits and delays in patient care services and reduce wastes in resources which can then be allocated to other needy areas.

Thus establishing a comprehensive picture of information flow within a given medical setting can help identify problematic areas so that resources can be more efficiently and effectively allocated for improvement and also can help decision-makers to develop effective workplace practices and establish requirements for necessary supporting tools. Thus, the InfoFlow Framework, an example utility of which was illustrated in Section 5.2, can be useful as a tool for developing such a comprehensive picture by allowing a domain analyst to focus on key elements of the workplace and associated workplace practices and allowing researchers to flexibly re-configure the factors for studying the information flow and identifying areas for improvements in their specific setting. For instance, a possible outcome could be systematic check points at appropriate stages of the information flow to ensure that correct information is being communicated through the right people and/or artefacts via the right communication mode in the right place and at the right time. However, to identify if information is missing is generally more difficult because in most cases, it is only discovered in hindsight investigations. Yet, the thorough investigation of information flow offered by the InfoFlow Framework has the potential to help uncover these *unrecognized* information needs as well (Forsythe et al. 1992).

5.4 Chapter Summary

The InfoFlow Framework presented in this chapter was built upon our understanding of the dynamics of information flow acquired in our own investigations of shift changes and collaborative work in nursing operations, as well as findings from past research. This framework can guide the evaluation of the elements and their interrelationship during shift change, which could facilitate comparative studies, identification of potential problem areas, and targeted intervention. The framework provides a set of factors that can be reconfigured to meet the needs and characteristics of different settings. It specifies six essential components of information flow. These are information, personnel, artefact, spatiality, temporality, and communication mode. However, these factors are not exhaustive and other factors may also impact the information flow. I illustrated the use of the framework by structuring it as a set of questions for generating coherent descriptions. I then discussed the InfoFlow Framework in terms of improving healthcare quality, specifically on how the InfoFlow Framework that offers thorough investigation of information flow in medical settings can help improve the safety and the timeliness of patient care. I anticipate that this framework will provide the community with a systematic means to study information flow in the medical setting and to identify opportunities for improving healthcare quality.

To illustrate other utilities of the InfoFlow Framework, I will apply the framework in the next two chapters, first as a tool to aid in the analysis of data generated in a study that assesses a newly deployed mobile voice communication technology, then to show how it can be used to inform the design of new technologies.

Chapter 6. InfoFlow Framework to Evaluate a Mobile Voice Communication system

The InfoFlow Framework presented in Chapter 5 was developed upon the field study presented in Chapter 3 that investigated the fundamental dynamics of the information flow across nurses' shifts and a distilment of past literature. This framework can be used to provide a coherent description of information flow during shift change, has the potential to be useful as a tool to aid assessing current technology use and to inform the design of new technologies for supporting information flow. In this chapter I applied the InfoFlow Framework in the analysis of the data collected during a field study on the deployment of a mobile voice communication system, Vocera. I used a set of communication strategies associated with the InfoFlow Framework that were widely used by nurses in our study ward when carrying out their work. Therefore, with the deployment of Vocera, it provided me an excellent opportunity to conduct a third-party study on how this mobile communication technology impacted the nurses' communication and information flow in the study ward where the nurses are often spatially distributed over different ward wings. I expected that they would take advantage of the hands-free voice communication system to receive updates from their outgoing coworkers without physically moving into face-to-face reporting as previously observed (Tang and Carpendale 2007a, Tang and Carpendale 2008a).

The current study was conducted in the same hospital ward described in Section 3.1. I will first describe the technology under study and the methodology. I will then present the findings in terms of a set of communication strategies derived from the InfoFlow Framework, followed by highlights on technology design.

(a) (b)

Figure 6.1 (a) A Vocera badge (source: http://www.vocera.com) (b) Pressing the Vocera button to place a call

6.1 Vocera Communication Technology

The technology deployed in the study ward was Vocera® communications system. It uses voice recognition and wearable communication badges running on a wifi network for making two-way conversations with coworkers using natural spoken commands. Vocera badges are compact, lightweight, and have a single button (Figure 6.1a). They can be worn with a lanyard (Figure 6.1b) or clipped on a shirt collar. One must first log on to the system. For example, Mary just came on shift. She went to the shift change room to sign out a Vocera badge and put it around her neck. To log on, she pressed the button on the Vocera and the automated operator (a.k.a. the genie) responded, "Please state your name." Mary said, "Mary Smith." Genie then replied, "You are now logged on."

To place a call, one has to press the button and give a verbal command to the automated operator (Figure 6.1b). The genie has to recognize the voice command; it then searches the database before connection is made for a two-way voice communication. No other physical manipulation is needed. Thus, once the voice link is established, the conversing parties can continue their task-at-hand. To terminate the connection, one party has to press the button. The following vignette shows how connection on Vocera is made.

Mary needed to talk to her colleague, Susan, who was working in another ward wing. Mary pressed the button on her Vocera. The genie responded, "Vocera" and she placed the command, "Call Susan." Genie replied, "Finding." Then on Susan's Vocera, an audible signal "Ding" was sounded to alert Susan, followed by the genie asking, "Can you talk to Mary?" If Susan could accept the call, she would say, "Yes". Mary and Susan could then talk directly.

Vocera also allows callers to leave a message, to broadcast to a specific group and to forward all the calls to a specific person. Also, built-in fun tunes will be played in response to specific commands, e.g., star-trek tunes played to "Beam me up!"

6.2 Methodology

This study was conducted in the first week (first stage) and the fifth month (second stage) of Vocera's deployment. Eight and twelve observational sessions were conducted respectively, each lasted 2 to 4 hours. The observations took place during regular shift periods, shift changes, and meal breaks.

6.2.1 Participants

Participants in the first stage were 3 unit clerks, 9 nursing aids, 36 nurses, and 1 patient care manager whereas participants in the second stage were 3 unit clerks, 7 nursing aids, 37 nurses, and 2 patient care managers. 1 unit clerk, 4 nursing aids, 17 nurses, and 1 manager participated in both stages. All the participants carried a Vocera badge during their shift.

6.2.2 Methods

Observations and interviews were used to find out how the participants used the system. Field notes were taken with pen and paper. The fact that this mobile voice communication system required minimal and subtle physical interactions from the participants made the field study complex and challenging as it was often unclear when they were communicating over Vocera. The distributed layout of the ward also made it difficult to observe two-way conversations. Observations were primarily taken place around the central nursing station as many Vocera communications were initiated in response to incoming phone calls. With its central location, it was easier to locate the respondents who were often distributed in the ward wings. Because most conversations were brief, the contextual information was usually missing and could only be recollected from follow-up interviews with the participants. Thus, the data collection was based on observable events and subsequent informal interviews with the participants for the communication motives and details. The findings of the two stages are highly similar, with a few differences which are highlighted in the findings section.

I first used open coding to analyze the collected data, based on an initial set of codes. New codes were created when the initial codes did not fit the observed events. Some examples of the codes are [BAD VOICE RECOGNITION], [CHECK AVAILABILITY], and [TRANSMISSION LATENCY]. The codes were then grouped under relevant communication strategies, each associated with a factor of the InfoFlow Framework. The codes that were grouped for each communication strategy were inspected for causal relationships or sequential occurrence of the events. The ordered event codes and the standalone ones were then organized using a fish-bone diagram (Ishikawa 1960s) as shown in Figure 6.2, with the six factors of the InfoFlow Framework, each representing a communication strategy, contributing the structure.

Color is used to differentiate positive and negative or unexpected phenomena. The negative or unexpected phenomena are shown in darker backgrounds. Since the displayed data includes observed events and series of events showing causal relationships that are a result of Vocera deployment, sequential events are to be read from one end towards the fishbone for each framework factor. For example, for the Communication Mode fishbone in the bottom right of Figure 6.2, since most participants regarded Vocera as their primary communication channel, the intercom broadcast was then treated as ambient noises which in turn led to two outcomes: nurses working on the floor ignored the intercom paging and unit clerks had to sound panic to draw attention. Similarly, on the left side of the Temporality fishbone, due to transmission latency, nurses had to speak slower than their natural speech. Therefore with the casual and ordered relationships of the displayed events, together with the use of color shades, the fish-bone representation provided an overview visualization of Vocera deployment as to why Vocera was or was not adopted as a mobile voice communication device (right end of the main fishbone). The visualization also helped to focus the analysis of the phenomena impacted by each framework factor.

6.3 Findings

From the observations, I identified many communication strategies, which resonate with some aspects of the InfoFlow framework. The six framework factors were all associated with a primary strategy for coordinating the communication on the ward as follows. The associated framework factor is italicized in each communication strategy.

- Choosing appropriate *artefacts* for information flow;
- Choosing an appropriate *communication medium*;
- Identifying and locating *personnel* to communicate;
- Off-loading *information* to the intended recipient;
- Minimizing *spatial* movements;
- *Prioritizing* and *scheduling* activities.

Because of this association between the Vocera observations and the framework's communication strategies, I use the structure of the framework to report the findings. While the InfoFlow framework allows a thorough analysis by understanding the inter-relationship between the six factors, one drawback is that these inter-relations contain overlaps. However this helps ensure relevant phenomena were properly considered. To establish previous communication practices, I first describe the communications as occurring before deploying Vocera using the framework's communication strategies as the structure, then report the impact of Vocera on the information flow and communication strategies. This helps define the changes that arose with the use of Vocera.

6.3.1 Pre- Vocera Communication

6.3.1.1 Choosing appropriate *artefacts* for information flow

Communication artefacts available before Vocera was deployed were telephones and computers at the nursing station and along the ward wings, an intercom at the nursing station, and portable paper notes. Cell phone use was not allowed while on duty. Telephones in the ward could be used to make internal calls within the hospital and to the outside. Internal calls required only an extension code while all external calls required a prefix “9” followed by the phone number. The intercom allowed overhead broadcast of messages from the nursing station over the entire ward with the exception of patient rooms. This design was deliberate so as not to interfere with patients’ rest. Patients could also communicate with the nursing station via the intercom from their room. An online text paging system was also available for contacting physicians.

Most communication from outside the ward came through telephones at the nursing station. When a phone call came in, a unit clerk would most likely use the intercom to broadcast for the attention of a specific clinician, if known, followed by the targeted clinician either calling the nursing station from his/her ward wing or spatially moving into face-to-face interaction at the nursing station. Personal paper notes were also pervasively used as an intermediary notepad by all the nurses and unit clerks in the course of their work for recording information (e.g., a patient’s pain level) that needed to be relayed to specific clinicians or to be documented later, and required communicative events, e.g., appointment scheduling.

6.3.1.2 Choosing an appropriate *communication medium*

Face-to face interactions, point-to-point closed telephone links, one-way broadcast over the intercom, and digital paging through texts for physicians were available in the ward. Unfortunately, the most effective face-to-face communication is not always possible due to the distributed nature of medical work. But telephone communication still allows collaborators to synchronously clarify, elaborate, and confirm information. With its point-to-point closed connection, a telephone is considered an appropriate medium to communicate private patient information. However, as nurses were always on their feet, they were mostly unavailable to converse over the phone. Therefore, broadcasting through the intercom provided convenience to initiate connection with clinicians. However, because of its lack of a feedback channel, clinicians could only respond through another medium, typically through telephone or by spatially moving into face-to-face communication. The effectiveness of this broadcast medium was also limited by the presence of "dead zones" inside patient rooms. Therefore the only way to ascertain proper receipt of the broadcast communication was to receive feedback from the intended recipient via another medium. Broadcasts were also interruptive to clinicians who were not the intended recipients as they would naturally slow down their task-at-hand to pay attention to the broadcast and only resume to normal pace after they realized that they were not the intended recipient. Such an interruptive work environment could impede one's work flow. The public nature of intercom broadcast also limits the kind of information that can be communicated. If the information would jeopardize a patient's privacy, the broadcast can only be an invitation for relevant clinician, leaving communication of the content for a more appropriate medium.

Nevertheless, the value of overhead broadcast was evident in emergency situations to coordinate rescue operations. When a patient became critically ill, the primary care nurse would immediately press the "Coding" button available in every patient room. In response, the hospital would issue a hospital-wide broadcast, "Code Blue, Unit 38." The Code Blue [Resuscitation] Team would then hear the broadcast and rush to the specific ward immediately.

6.3.1.3 Identifying and locating *personnel* to communicate

Multi-disciplinary collaboration is prevalent in modern medicine. Thus, the nursing station plays a crucial role as all incoming communications are first received there. The following vignette illustrates how incoming calls are typically handled.

Jane, the unit clerk on duty, received a phone call from the radiology department looking for the primary care nurse for the patient in room 3840. Jane looked up the large assignment board across the nursing station and identified that it was Carrie. She then put the phone call on hold, picked up the intercom receiver and made a broadcast with a directed message, "Carrie, radiology is on the phone for 40 [room 3840]". Carrie was in her ward wing so she picked up the phone there to call Jane, "Can you transfer it to B [ward wing B]? She then hung up. The phone in the ward wing then rang. Carrie picked it up and talked to the radiologist. [However if Carrie was inside a patient room at the time, she would have missed the broadcast. Without getting a response from Carrie, Jane would either make another broadcast (same broadcast or to ask other people to relay the message) or to find Carrie herself.]

Sometimes, the unit clerk might not know right away who the phone call was for. For instance, a physician called, *"Someone paged me?"* Jane would then simply make an undirected broadcast to identify the concerned clinician, *"Who paged Dr. Smith? She's on the phone."*

As medical work is highly collaborative, nurses often require assistance from their colleagues in the ward. This type of connecting with colleagues is frequent.

"*Carrie needed help, but she did not see any colleagues nearby. So she would either call or go to the nursing station to ask Jane to broadcast for assistance on her behalf. Alternatively Carrie could go to find her colleagues in person. But this usually took longer time and more effort."*

Thus, to identify and to locate collaborators often required the use of multiple communication channels or spatial movements with the existing technologies.

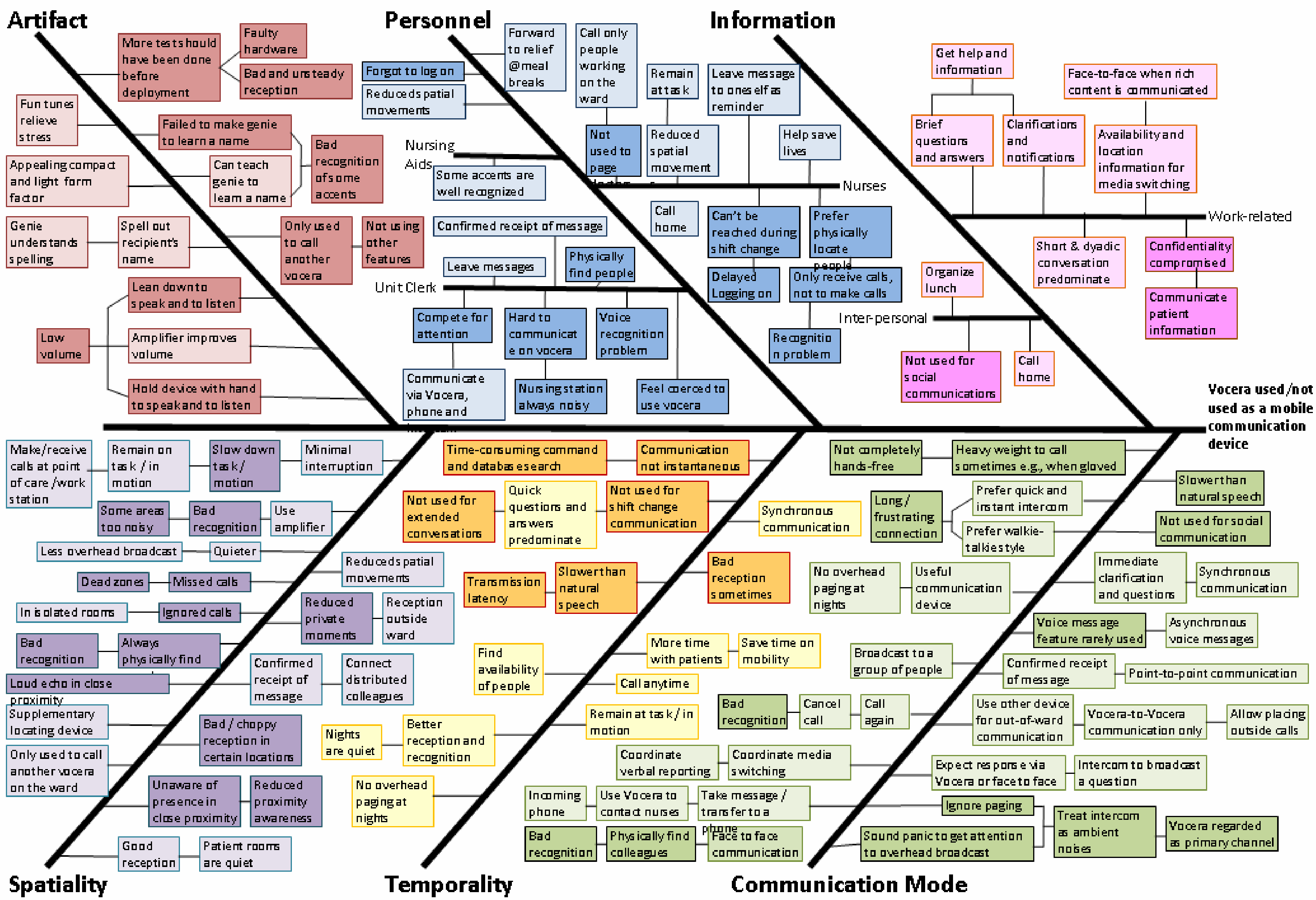


Figure 6.2 A fish bone diagram used for visualizing and analyzing the findings of the Vocera deployment (Negative or unexpected phenomena in darker backgrounds)

6.3.1.4 Off-loading information to intended recipient

The centrally located nursing station serves as the reception desk and the information hub of the ward. The “gatekeeper” function, discharged by unit clerks, plays an important role to ensure communication is properly received and routed so that patient care is carried out efficiently. For example, the unit clerk receiving a phone call from the pharmacy regarding a patient’s newly prescribed medication may take the message and then relay it to the primary care nurse, or broadcast for the primary care nurse to ask for routing directions. Such information off-loading is a common and frequent practice in the flow of information.

Although each nurse was assigned with a specific number of patients in each shift, nurses at the ward are highly collaborative. I observed many instances where a nurse noticed another nurse’s patient needing assistance or attention. S/he would then go to find the colleague to relay the information. In situations where the nurse was too busy at the time, she would make use of technologies, e.g., to phone the nursing station to off-load the information.

6.3.1.5 Minimizing *spatial* movements

Technology-mediated communications are widely used to connect distributed collaborators without spatial movement. Broadcasts on the intercom allow simultaneous communication to a large audience, thus reducing the need to spatially move to look for intended recipient(s) of information. Responses could also be made through telephone although sometimes face-to-face communication was necessary. However, when no response was received for the broadcast, mobility was likely required to physically look for the intended recipient, which would be more costly in time and effort.

Though nurses often need to move around to look for information and resources, when possible they found workarounds to reduce their mobility. When the situation was not time critical, they would postpone their information seeking and dissemination activities until several demands made the trip worthwhile. Such poly-motivated mobility practice (Ash et al. 2004, Bardram 1997) can considerably save nurses’ time. The use of paper notes as a reminder helped facilitate this practice of grouping tasks which is indeed an integral part of organized and efficient nursing practice.

6.3.1.6 *Prioritizing* and *scheduling* activities

Nursing care involves many planned as well as spontaneous activities relevant to multiple patients' diagnosis, treatment, and nursing. These activities include actual care procedures and communication events that must be temporally coordinated, synchronized, and prioritized. Fluctuations in a patient's illness require nurses to dynamically change their care plan activities, which in turn must also be communicated to relevant clinicians who would then have to adjust their work plan. Intercom broadcasts and face-to-face communication were frequently used to coordinate clinicians working on the ward whereas off-ward clinicians were typically contacted through telephones.

6.3.2 Communication with Vocera system

Vocera system was deployed among unit clerks, nursing staff, and a small number of off-site clinicians. For brevity, I use *members* to refer to the people in this Vocera community. As the majority of communications within the ward occurred between the nurses, unit clerks, and nursing aids, this study focused on their communication practices. In fact, I found communications on Vocera system only took place between members working on the ward as they were unaware which off-site clinicians were also members. The deployment of this wireless mobile communication system was adopted with mixed responses, ranging from *"I love it!"* to *"This is the crappiest thing!"*

6.3.2.1 Choosing appropriate *artefacts* for information flow

Vocera provided additional communication resource that is portable and can be used anytime and anywhere while the old technologies continued to be in use. However, the voice recognition was found to be suboptimal and presented a non-trivial problem that all members had to deal with at varying difficulties. The genie (i.e. the automated operator) frequently did not understand the spoken command. This voice recognition problem was not limited to non-native members speaking with an accent. Native English speakers also found this problem occurred too frequently and caused much mental stress and frustration. When the genie misinterpreted the spoken command, the caller could repeat the command but most members would just terminate the call and restart another one. They said it was faster than waiting for the genie's instructions to repeat the command. Most members would try 2 to 3 times before they gave up and looked for alternatives to communicate, as illustrated in the following.

Jenny used her Vocera to call Patrick. "Call Patrick." "I'm sorry, I don't understand." Jenny terminated the call and restarted another one. "Call Patrick, Unit 38." "You want to call dietician in Unit 38?" She then stopped the call and told us, "How can Patrick be even close to dietician?" She then decided to find another way to reach Patrick. She did not know where Patrick was so she used the intercom at the nursing station. "Pat, can you please call Jenny?" Patrick got the message so he called Jenny on his Vocera. The connection was uneventful so the two talked on the voice link. [In situations where if Jenny knew where Patrick was, she typically just went to find him to talk face-to-face].

I received a wide range of affective responses towards the system, from loving it to hating it. The dramatic differences in the feedback largely hinged on their experiences with the voice recognition at connection. A few members found this connection experience so frustrating that they opted against using it for calling. But they still wore it so that other members could reach them. They also preferred the old technologies and would personally go to find their coworkers. But several said they felt coerced to have to visibly use Vocera and to express positive experience with it when it was not in reality.

Although Vocera could be used to broadcast to all the members or a designated subgroup, e.g., the nursing aids, the intercom was still preferred because it was easy to use. Moreover, as Vocera was not truly hands-free, members often had to first take off their gloves which are necessary in many clinical procedures before pressing the button on their badge to start a connection. Thus, some nurses found it cumbersome and complicated to call on Vocera while they were working.

(a) (b)

Figure 6.3 Holding Vocera badge (a) to talk and (b) to listen

The ambient noise was also relevant when deciding which communication artefact to use. Voice recognition got worse in noisy areas and the volume of Vocera voice link was generally low. Thus members always had to either lean their head towards the badge or hold the badge up close to their mouth to speak (Figure 6.3a) or their ear to listen (Figure 6.3b). A nurse stated, *"The volume is too low! When I'm working with a patient, I can't hear it and I can't hold it up to listen…"*

In the early stage, members were found to appreciate the playful moments when built-in fun tunes were played. They found the tunes helped ease their stress. But members were not seen to play these fun tunes in the fifth month of its deployment. It was not too surprising as this is quite typical when the novelty of a technology faded away.

6.3.2.2 Choosing an appropriate *communication medium*

Vocera offered several communication media to the members in addition to those available through the old technologies. Communications conducted via Vocera were open such that people around could also hear the conversation. It allows open point-to-point communication between distributed members and broadcasting to the entire group or to a designated sub-group. It can be used to leave messages for a member who could then retrieve the messages through their Vocera badge. It can also be used to call to regular landlines and cell phones, with voice commands. At meal breaks, members can forward their calls to their relief's Vocera.

Calls made on Vocera are not instantaneous as the genie must first understand the voice command before making the connection. But members generally perceived it as a more efficient way to reach their coworkers than having to physically moving into conversation. Therefore members frequently used Vocera to connect with their colleagues who were always distributed. However, observable latency impeded the actual voice communications so they had to talk slower than normal, making it difficult to communicate detailed information. This is likely why no reporting activities were seen to take place using Vocera during shift changes. A nurse said, *"It's too slow... Unless you're sick and can't get up, then you'll use a Vocera to do that [shift reporting]!"* Also, although nurses could continue with their current task while using the technology, they had to somewhat slow it down.

The open voice link that can be overheard by people around was also detrimental for communicating private information. Thus, when detailed or private information was needed, members generally used Vocera to coordinate switching to another medium to continue the conversation. Nurses were frequently seen to use Vocera to negotiate when and where to meet for face-to-face shift reporting.

Members preferred broadcasting on the intercom rather than using Vocera as the former was easy to use. But Vocera would be used when the intercom was not an option such as during night shifts. Intercom use was forbidden at nights so as not to wake patients up because doors might be open even though intercom broadcast basically could not be heard inside the rooms. With its broadcasting utility, Vocera was used in a real situation making a life-and-death difference.

"The incident occurred during night shift, a time when the staff is busy and scattered throughout the floor. A seriously ill and confused patient disconnected himself from his IV and searched for an exit. Security was called, as he was a risk to himself and others. The patient went out an exit and down to the next floor, where the door was locked, and proceeded to collapse. Vocera was used to communicate with and coordinate

the staff, to bring oxygen and an O2 saturation monitor to the patient, obtain supplies for the IV site which was bleeding, obtain a wheelchair to take the patient from the second floor to the third floor and keep the Code 66 [an emergency code] team, who had been called when the patient collapsed, apprised of the movements." The nurse who initiated and coordinated the rescue operation said "this rescue operation would not have been possible without the Vocera System".

Despite such encouraging usefulness of the system, some members were still entirely disappointed with it. For example, *"It [Vocera] is the worst thing ever happened. It [the genie] just doesn't understand. The noises here are too loud that they never work properly."*

Vocera supports asynchronous communication through voice messages but only unit clerks were seen to leave messages for other members. This is understandable as unit clerks had to handle continual incoming calls among clerical duties, and leaving a message is an easy and direct way to off-load information to intended recipient(s). However, a nurse was observed leaving messages for herself regarding patients' medical conditions. She said it was too time-consuming to write the details down but it was easy to press a button and leave a message. For example, she could just talk to Vocera about the size, color, shape and amount of fluid coming out of the wound while she was changing the dressing for a patient. Another nurse also said that "leaving messages for oneself" would be very useful when they were inside isolated rooms where they had to be gowned up and could not write anything down. But they could still press the button underneath their gown to record a message.

Vocera was rarely used to make phone calls as spoken commands must be first recognized by the genie to make the connection. Thus it is much easier to call on a phone. Only a few nurses were observed calling their families on Vocera to briefly exchange affections.

I was also told an interesting phenomenon as a result of the members being used to Vocera communications. Many members now treated the intercom medium as ambient noises. Many times when unit clerks used the intercom to broadcast a message, the members disregarded it. The unit clerk then had to sound panicked over the intercom for urgent matters in order to draw their attention.

6.3.2.3 Identifying and locating *personnel* to communicate

With Vocera, a member did not need to know where the other members were when establishing a voice link. The following vignette illustrates how the unit clerk handled incoming phone calls differently with Vocera.

Jane received a phone call from the radiology department looking for the primary care nurse for the patient in room 3840. Jane then looked up the board across the nursing station and found that it was Carrie. She put the phone call on hold, used her Vocera to call Carrie and asked how she would like to take the phone call. Carrie then asked her to transfer it to the phone in her ward wing. When the phone rang, Carrie picked it up and talked to the radiologist.

As opposed to broadcasting over the intercom and waiting for Carrie's response via another medium, Jane was able to connect with Carrie directly and negotiate in the same communication medium. Even if Carrie was inside a patient room at the time, she would not have missed the call on her Vocera. Thus, Vocera offered clear benefits in locating people. However, when communication via Vocera broke down, members would have to use the old communication technologies such as the intercom system. Vocera breakdown would then delay the communication process as people would usually have tried it several times before they gave up and reverted. Incoming phone calls can also be transferred to a member's Vocera. However, I did not see anyone using this feature in the study. In fact, most nurses were not aware of this feature; those who knew did not use it as they found it too complicated.

Nevertheless, many nurses considered the benefit of using Vocera to connect with their coworkers without physically finding them outweighed the frustrations experienced with the voice recognition at connection. Thus using Vocera to locate and check the availability of members represented a large fraction of Vocera use.

6.3.2.4 Off-loading *information* to intended recipient

The poly-motivated mobility pattern exhibited before the deployment of Vocera has transformed into many frequent and instantaneous off-loading of brief information through the synchronous voice link. Most conversations conducted over Vocera were short and dyadic. These conversations typically involved quick work-related questions, clarifications and notifications, location and availability information of a coworker so that further actions could be arranged. For example:

"Mary, can you go to 23 [Room 3823] to help Sara?" "Ok, I'll be there in 5 minutes."

"Where are you, Joe?" "I'm in [ward wing] A" "Can I come to give you a verbal [report]?" "Yeah!"

Members used Vocera to spontaneously seek information when necessary and they could also be certain that the information has been properly relayed and received through the synchronous communication. However, people were not seen to use the system to converse over rich information content. Rather, for longer and complex information exchange, they used Vocera to obtain location and availability information and then to determine if, when, and where a more detailed conversation (e.g., face-to-face) could occur.

Vocera is operated over an open voice link making it inappropriate for communicating private or confidential information. Before, unit clerks always relayed private patient information to other clinicians through telephone or face-to-face interactions. But Vocera conversations were also perceived as similar to the telephony. The fact that callers were usually unaware of their colleague's location would sometimes have unknowingly compromised the patients' privacy by sharing private information over the open voice link when other people were around the other end of the link. I was told of an incidence where a member used Vocera to inform a nurse that her patient's critical laboratory results had come back, not knowing that the nurse was in conversation with the patient's family. The nurse immediately saw an increased anxiety of the family. Thus she would prefer that such information not be communicated through the open voice link. Many nurses also reported situations when they were talking on Vocera with a colleague, the patient and their family mistook that the nurse was talking to them, thus causing confusion.

6.3.2.5 Minimizing *spatial* movements

Before using Vocera, one way to minimize spatial movements was by making poly-motivated communication trips. But the convenience offered by Vocera to reach their coworkers without spatially moving to find them allowed members to frequently and spontaneously connect with their coworkers while they were on their feet, accessing information or providing care. For instance, a nurse used it to call her outgoing colleague for clarifying a patient's treatment progress while continuing to read the patient's chart at the nursing station. Thus, members perceived a substantial decrease of distances they had to cover. One member stated:

"This device is so useful! It saves me a lot of walking and searching. Once I heard a beeping sound from an IV [infusion pump] in a patient room and the nurse was not around. I just used it [Vocera] to let the nurse know right away!"

In fact, preliminary measurements using pedometers carried by several nurses and nursing aids showed that Vocera reduced a nurse's mobility in an 8-hour shift from about 6680 to 3360 steps. Vocera was also useful when it was not safe to leave a patient while seeking help.

With Vocera, not only could members make and receive calls inside patient rooms, the reception was also reportedly better as patient rooms are generally quieter. With less overhead broadcast on the intercom, the ward has also become quieter in general. More importantly, the synchronous voice link provided instantaneous confirmation of receipt of information without making extra effort, e.g., going in person, to find out.

Vocera also reduced the trouble of "people hunt" that often occurred before when a person did not find the intended collaborator in the location where s/he was expected to be. The hunt would then continue on to the next expected location until the collaborator was correctly located. Instead, Vocera allowed members to first locate the intended collaborator before making any spatial movement for further communication.

"Before, I sometimes would go to a wing to find a nurse who was actually somewhere else, so I would have to keep searching…wasting so much time!"

"A lot of times, we walk all the way over to the other side of the ward to just see if somebody can come to help…"

However, a number of locations in the ward have been reported to be dead zones for Vocera. Members working there would then have to communicate in the old ways and use the old technologies. This also caused frustrations to other members who could not use Vocera to reach the members working in these areas.

An undesirable phenomenon as a result of the convenience of using Vocera to connect with another member was also observed. Many members have become less alert towards their physical surroundings. It was found that members have become less watchful about their close proximity for the presence of coworkers they wanted to communicate with. They seemed to have subconsciously regarded Vocera as the first choice for communication. I observed many incidences where the intended collaborator was just nearby, e.g., a few steps away, but the member made a Vocera call without first checking the surroundings for the presence of their colleague. This made the communication unnecessarily dependent and worse still, the more effective face-to-face interaction has become secondary to the technology-mediated communication.

6.3.2.6 *Prioritizing* and *scheduling* activities

Vocera allows impromptu conversation while members were working on a task or moving around the ward. Although the connection on Vocera was not truly instantaneous due to the need for voice command recognition, information could basically be communicated as soon as it was acquired. Thus members no longer had to postpone their information seeking or dissemination activities. Such ubiquitous communications also appeared to improve the timeliness of information flow for meeting the dynamic and time-sensitive needs of patient care.

Despite the frequent trouble of voice recognition, many members concurred that the time saved by using Vocera to locate and negotiate with people outweighed the slight connection latency. As a result, participants had more time to spend with their patients. *"It makes a huge difference! I can spend more time getting my work done now coz I don't need to go find people anymore…"*

6.4 Discussion

The findings of this study indicated mixed responses, although in general the Vocera technology was well-received. While Figure 6.2 provided an overview visualization of the technology deployment, the following discussion highlights several important findings of the study which help inform technology design to be discussed next.

6.4.1 Positive Impact

With Vocera, members could communicate with each other anytime and anywhere, supporting the time-critical and mobile nature of medical work. It basically allowed the members to continue their task-at-hand and reduce unnecessary mobility to locate and connect with their collaborators who were always on their feet (Bardram and Bossen 2005b). This study revealed more time for patient care with the savings in time searching for collaborators; previous literature indicated that such time saving led to improved medical safety (Hanada et al. 2006). Members also used Vocera to manage the conversational progress and negotiate availability for deciding when to switch media, typically to face-to-face communication (Bellotti and Bly 1996). The synchronous voice channel was frequently used for spontaneous quick questions, clarifications, and coordinating work, replacing the poly-motivated mobility practices (Ash et al. 2004, Bardram 1997). Thus, information was made available in a timely manner. Meanwhile, the instantaneous off-loading of information helped reduce memory load, which will likely decrease medical errors. Vocera also largely replaced the use of overhead broadcast which was interruptive and noisy. Thus Vocera brought about a more pleasant work environment which has been found to help improve work quality and workload (Hanada et al. 2006).

6.4.2 Life-and-death difference

Vocera's role in making a life-and-death difference as described in Section 6.3.2.2 showed that this communication technology has great value in medical work. Currently, Vocera is only deployed among the nursing staff in a single ward. The technology will likely benefit the prevalent multidisciplinary collaborations once it is widely adopted. However, the possibility and the extent to which such real-time communication mediated through technology such as Vocera may interrupt work and thus lead to increased errors, as reported in Coiera (2000), should also be investigated.

6.4.3 Unintended consequences

Vocera was perceived by most members as the primary communication mode between distributed collaborators. Thus they became less alert to overhead broadcast and the presence of collaborators nearby. These unintended consequences may have negative impact on the information flow (Ash et al. 2004). Thus, the intercom system may be designed to integrate with Vocera so that they complement with each other and at the same time serve as a backup should the other fails. Besides, contextual information of coworkers would be valuable for estimating their availability as well as their proximity before initiating communications. On the other hand, the unanticipated use of Vocera to leave messages for oneself indicated its potential to include an easy-to-use and retrievable recording feature that can effectively support the dynamic work.

6.4.4 Unrealized expectations

Members did not use Vocera for casual interactions with their coworkers in the first week of its deployment. But it was expected that social interaction would more frequently take place through Vocera when they became more familiar with the technology. I also predicted that the informal interaction would help improve the social awareness among the distributed members. However, social communications on Vocera did not occur as was expected in its fifth month of use because the nurses were usually busy and did not have time for social interactions at work. They only caught up with their colleagues during shift changes and meal breaks. The nurses also did not conduct their shift reporting on Vocera because of the inferior reception quality and transmission latency problem. Instead, nurses mostly used Vocera to negotiate availability and then to switch to another communication medium for the reporting.

6.4.5 Primary technology problem

Communications on Vocera helped improve information flow in the study ward. Yet, the biggest hurdle was to make the connection. This led to some members' hostility towards its adoption and their opting to only use the technology as a receiver. An experienced nurse commented, *"I think they shouldn't use this thing [Vocera] until the problems are fixed because people are getting really frustrated"*. To them, the technology was more a hindrance than a benefit (Morán et al. 2007).

6.4.6 Design guidelines

Since Vocera offers clear benefits and has great potential in supporting the time-critical and dynamic medical work, I propose several design guidelines to influence the (re)design process for this type of technology to better support information flow among the members.

6.4.6.1 Design for easy connection

Vocera was designed for ubiquitous communication across distance. Therefore, it is vital that connection can be made with ease and confidence. Since the current state of voice recognition technology is still limited, I suggest providing an alternative command input to ensure reliable connection. Examples include providing an address book of all members and speed dials for frequently called members such as the nursing station.

6.4.6.2 Design for heterogeneous adopters

The current Vocera system provides a homogeneous product to a group of heterogeneous members whose job nature and mobility patterns are quite different. Knowing and designing technologies for the differences in their interactions, activities and use is important so that everyone benefits directly (Grudin 1988).

A communication device is ideally compact and simple to use for mobile workers such as nurses. But working primarily at the stationary information hub mainly to properly route incoming communications to intended recipients, unit clerks could use a different device which allow them to easily connect with other member's Vocera without facing the voice recognition problem. Being able to connect reliably would greatly facilitate the information flow through the central hub while maintaining the benefits of Vocera use. This is particularly important when Vocera is to be deployed among other groups of clinicians whose job and mobility characteristics may also be different.

6.4.6.3 Design for contextual awareness

An up-to-the-moment awareness of coworkers' activities and locations would help coordinate communication and be valuable when interruptions could be detrimental or unwelcome, e.g., when providing comfort to a terminally-ill patient. In fact, it has been reported that psychological costs associated with interruption at work could lead to diversion of attention, forgetfulness, and errors (Coiera and Tombs 1998). Meanwhile, we should also investigate possible ethical and privacy issues that may be associated with the deployment of such context-aware technology.

6.5 Chapter Summary

This chapter presented an observational study conducted at two different time frames to evaluate how a mobile voice technology impacted communication and information flow on the study ward. It also showed that the InfoFlow Framework presented in the previous chapter can be used to guide the assessment of new technologies. I first derived a set of communication strategies commonly used by the nurses in our study ward; each strategy was associated with a factor of the framework. I then organized the findings around the framework factors in a fishbone diagram to present an overview visualization of Vocera deployment and observed events showing causal relationship and ordered sequence as a result of the deployment.

The technology was adopted with varied responses, from loving it to hating it. The negative responses were mainly a result of their dissatisfaction towards the connection experience whereas the positive adoption was attributed to the convenience of connecting with other coworkers without having to physically move to locate them. The findings from this study help inform the (re)design of similar technology to better support information flow in the dynamic and time-critical hospital settings, and serve as a guide for Vocera deployment in other hospital wards. For example, this study revealed the importance of supporting easy connection of the mobile device because frequent communication among clinicians is often required for work accomplishment. Designing for heterogeneous adopters of the system should also be considered to meet their varying needs and job nature while providing contextual information would reduce unnecessary or inappropriate interruptions to peer colleagues. In the next chapter, I will use the InfoFlow Framework to guide the technology design, based on the findings of the studies presented in previous chapters, for supporting nurses' information flow.

Chapter 7. InFlow Framework to Generate Technology Design

In Chapter 6, I used the InfoFlow Framework to derive a set of communication strategies which were widely used by the participants during our field studies. I then used these communication strategies to organize and analyse the impact of the deployment of the Vocera communication system on the nurses' communication and information flow. In this chapter, I will use the same framework to first generate a set of design goals based on the findings from previous studies presented in Chapter 3, 4, and 6. The basis of my design goals lies in the importance of supporting work practices that nurses have established and adjusted through their practical experience on the job. These design goals are then used to guide the development of technology designs for enhancing nurses' information flow. The following summarizes the design goals; each of which is associated with a factor of the InfoFlow Framework.

- To support *personnel*'s actual work practices;
- To preserve existing *artefacts*' desirable affordances for interaction;
- To enhance accessibility of *spatially* distributed information;
- To facilitate *timely* retrieval and entry of information;
- To support *information* use offered by existing artefacts for patient care;
- To provide preferred *communication modes* to support work practices.

7.1 Design Goals

As patient care delivery often requires clinicians to frequently access information that is ever-changing in response to fluctuations in patients' conditions, digital technology is thus a good candidate to allow consistent, integrated, distributed, and timely sharing of information among multidisciplinary clinicians. The three field studies that were conducted each separately informed targeted design guidelines for improving particular practices or technology, as described in Chapters 3, 4, and 6. Together they offer valuable insights on how technology may be designed to provide more comprehensive support for nurses' information flow.

My goals are to design technologies to support nurses' work practices and to take advantage of the digital capabilities to offer timely, distributed, and more frequent information access to consistent information. Based on the InfoFlow Framework, I identify useful characteristics of nurses' information flow and important work practices that are crucial to their work. They are then described around the framework factors for the generation of the design goals, which are described next.

7.1.1 Personnel

The premise of this research is to support nurses' work practices that have evolved over time to facilitate the conduct of their work. In this regard, the field studies clearly indicated the importance of using paper and pen to prepare and customize personal notes and to achieve work effectively. Thus, my first design goal aims to allow nurses to retain their familiar use of pen and paper as an integral part of their information flow practices. Besides, as interpersonal communication is vital for the delivery of patient care such as when providing comfort to patients, my technology design takes consideration in supporting interpersonal communication.

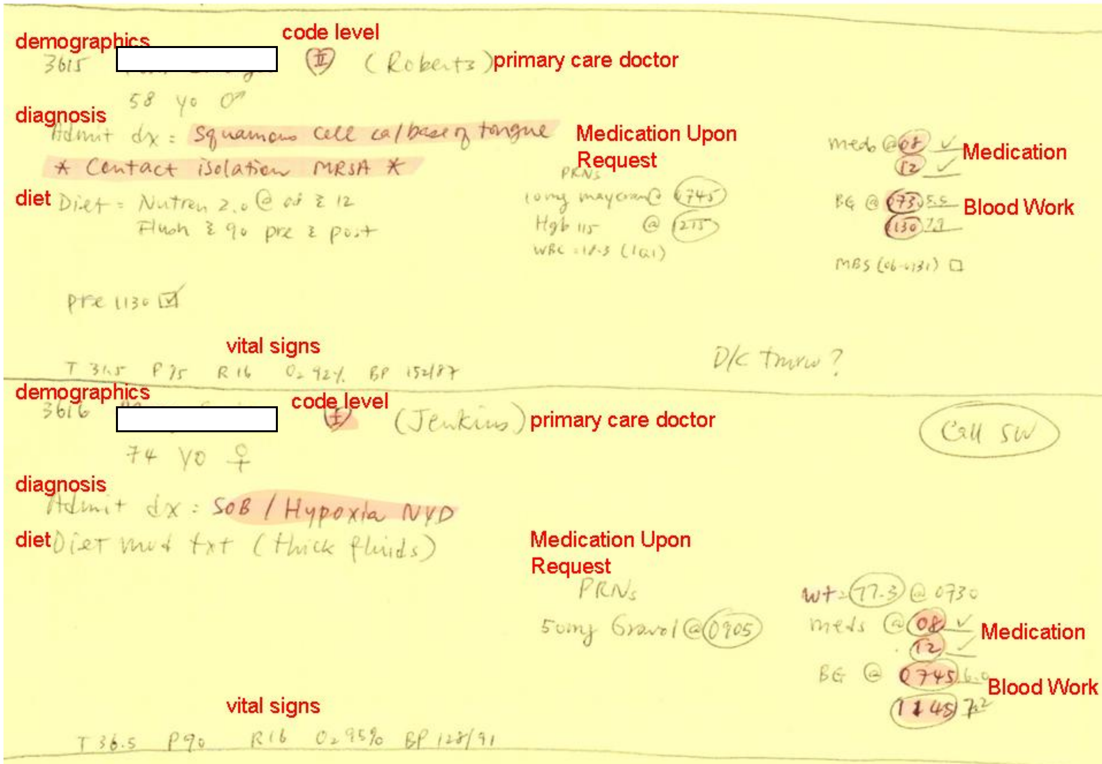


Figure 7.1 A simulated personal notes showing individual personnel's customized information layout (same as Figure 3.17). Red typed labels are used to indicate specific locations of different kinds of information (e.g., demographics at top left, followed by diagnosis and diet, whereas medication and blood work in the bottom right) (patient names are masked)

Goal 1: **To support *personnel*'s actual work practices**

Sub-goal 1.1: To support individual customization of notes

The practice of using pen and paper to prepare personal notes has been repeatedly found to serve as the primary information source at points of care, partly because they can be easily customized for specific information organization to facilitate information retrieval (Figure 7.1), partly because of their flexible and portable affordances for supporting the mobile and dynamic hospital work (Harper el al. 1997, Tang and Carpendale 2008, Zamarripa et al. 2007), and partly because they support writing-as-thinking as an important cognitive process in patient care (Ash et al. 2004). In contrast, the structured and hierarchical design of current digital information systems has been reported to impede information retrieval and entry (Bossen 2006, Tang and Carpendale 2008a).

Therefore, clinicians' practice of customizing personal notes for use in their shift work should be preserved.

Sub-goal 1.2: To support interpersonal communication

Interacting with patients is fundamental to quality patient care, such as when making assessments and when performing comfort work (Strauss et al. 1985). The computer-on-wheels deployed in our study ward was found to impede communication with patients with its bulky and rigid structure (Tang and Carpendale 2008a). Although hand-held computers are less intrusive than desktop computers, they were found to impede doctor-patient conversations at consultations (Houston et al. 2003) such that doctors had difficulty in continuing conversations with their patients when they had to focus on their computer for more than five seconds (Newman and Cairns 2009). Thus, technologies that allow clinicians to easily interweave with patient care activities would be beneficial.

7.1.2 Artefacts

Previous literature and this research have identified the use of a variety of artefacts in workplaces for coordinating information flow (see Section 2.3.4). In fact, many work practices started with the organizational introduction of various artefacts into the workplace with the goal to provide functional support for accomplishing work (Jones and Nemeth 2005). However, these artefacts often failed to support many subtle non-functional or less-functional aspects of work which are nonetheless crucial to achieving work. For example, patient charts typically do not allow clinicians to customize the information layout or to write personal reminders for their work. Thus, existing artefacts may evolve through purposeful reconfiguration to meet the practical needs of personnel to get their work done. Work practices may also be altered through the introduction of "personal" or "improvised" artefacts by individual personnel or a group of personnel to the workplace when there is a perceived need for an "improved" artefact to better support their actual work practices (Jones and Nemeth 2005), such as the working record created by clinicians of different disciplines to provide their own "clinician-centric views of work" (Fitzpatrick 2004). Thus, my second design goal is to identify useful affordances offered by existing information artefacts for facilitating information flow that should be preserved in the new technological system.

Goal 2: **To preserve existing *artefacts*' desirable affordances for interaction**

The following desirable affordances were selected from the information artefacts currently used in our study ward (Table 7.1). *Patient Charts* provide the flexibility for making free-form annotations and sketches which are useful for supplementing and sometimes substituting textual information. They are also an important central repository of paper documents that form part of a patient's official medical record. *Electronic health records*, which can be accessed through desktop computers and computers-on-wheels, are valuable for providing distributed access and sharing of information among multidisciplinary clinicians. Traditional *whiteboards* used for displaying handwritten nursing shift reports also offer important awareness information of patients' conditions on the ward. *Vocera* allows distributed clinicians to engage in real-time and spontaneous conversations. The unexpected use of its voice messaging feature for 'note-taking' of rich information contents at work shows its potential in enhancing nurses' information flow. Lastly, the desirable qualities of informal *personal notes,* created with paper and pen, should be maintained, as far as possible, i.e., being easy to carry around, being flexibly customized and used, and being easily integrated with ongoing patient care without impeding interactions with patients. In addition, I also identify possible enhancements that may be considered in the technology design (Table 7.1, rightmost column).

Table 7.1 Qualities of existing artefacts to preserve and to enhance in technology design

	Desirable affordances to preserve	Enhancements
Patient chart	• free-form annotations allow flexible information entry • repository for paper documents	• inscriptions centrally archived • retrievable in distributed locations
Electronic Health Record	• frequent and distributed access • data integrity and information consistency • information representations to meet different needs	• Provide familiar information layout • Easy conversion from handwriting to digital texts • minimize navigation when entering and retrieving information
Desktop computers	• distributed access to EHR	• offer alternative intuitive interaction mechanism, e.g., stylus input

COWs	• distributed access to EHR • used as a mobile device when needed	• offer alternative intuitive interaction mechanism • streamline form factor to facilitate manoeuvring • provide comfortable seating
Whiteboard	• overview visualization offers a 'picture of the ward'	• shift reports composed and retrieved in distributed locations • archived for review
Vocera	• connect distributed clinicians • voice message to record rich information content for later processing and review	• enhance voice recording as 'note-taking' device • provide hands-free information retrieval
Personal notes	• pen and paper interaction to allow nurses to build work plan • use as bedside information source and opportune notepad • use for reporting	• facilitate information conversion from paper to digital medium

7.1.3 Spatiality

Modern medicine often requires clinicians to locally move around to get in touch with their collaborators, to maintain awareness of each other, to access information inscribed in coordinative artefacts, to secure needed resources, and to execute specific actions in order to accomplish work (Bardram and Bossen 2003, Bardram and Bossen 2005a, Bardram and Bossen 2005b, Bellotti and Bly 1996, Bossen 2002, Gonzalez et al. 2005, Luff and Heath 1998, Xiao 2005). Thus, it is often difficult and sometimes impossible for clinicians who are always on their feet to access information that is only available in specific locations. This led us to derive my third design goal to enhance accessibility of spatially distributed information.

Goal 3: **To enhance accessibility of *spatially* distributed information**

Sub-goal 3.1: To provide distributed information access

While EHRs are increasingly replacing paper medical records to provide distributed and timely sharing of up-to-date information (Berg 1999, Ellingsen and Monterio 2001, Harper et al. 1997, Helleso and Ruland 2001, Sellen and Harper 2002, Skov and Haegh

2006), some non-digital documentations are still in use containing vital patient care information in addition to that available in the EHRs. To access such non-digital information, e.g., in paper charts and on whiteboards, clinicians must spatially move to where specific information is available. Obviously, such mobility consumes clinicians' valuable time and is best minimized for the benefit of patient care. Therefore, patient care could be improved if information residing in distributed information artefacts can be accessed at remote locations, thus minimizing unnecessary spatial movements such as that made to simply get someone to come over to help and in such case, the spatial movement could also be posing danger to the patients.

Sub-goal 3.2: To streamline information navigation

Current information system interfaces often require cumbersome navigation to access information. If navigation along a hierarchical information system can be reduced while still providing access to needed information, the time cost of information access could be reduced and in turn could improve the quality of patient care.

7.1.4 Temporality

"The vast subdivision of labour which characterizes our technology requires coordination in time and space – neither axis alone is adequate" (Cottrell 1939). As such, much collaborative work is built upon the temporal feature of tasks for planning, organizing, coordinating, and conducting work activities (Bardram 2000, Orlikowski and Yates 2002, Reddy et al. 2006). For example, it often requires careful planning and management for the right configuration of people, resources, knowledge and place to be temporally coordinated in order that patient care can be delivered accordingly (Bardram and Bossen 2003, Bardram and Bossen 2005b). Therefore, technology that enables timely flow of information could facilitate the conduct of scheduled work activities, which could in turn improve the quality of patient care. I focus on the timely availability of information for carrying out work, opportune entry of information at points of care, and support for task scheduling to facilitate work coordination.

Goal 4: **To facilitate *timely* retrieval and entry of information**

Sub-goal 4.1: To support timely information retrieval

Efficient information retrieval at points of care is crucial for quality patient care. However, current digital devices fall short in offering an efficient means for information retrieval, largely due to the usability issues that require tedious log-in process and subsequent navigation along the hierarchical information structure. Information retrieval is also impeded if network connectivity is unsteady or sub-optimal, as was the case in our own study (Tang and Carpendale 2008a). Thus, nurses in our study ward persistently relied on the old-fashioned paper notes even after the deployment of mobile computers-on-wheels. Although paper artefacts are limited by the amount of information that they can hold and the inscribed information has to be manually transposed to the digital medium, these paper artefacts were found to effectively facilitate timely retrieval of information at bedside.

Sub-goal 4.2: To facilitate paper-digital conversion

At some point, information gathered during a shift must be fed into the EHRs. Currently, this is done by manually transposing handwritten information to the digital record, which is time-consuming constituting a considerable segment (around 13-28%) of nursing activities (Allen 1998, Strople and Ottani 2006). Therefore, a system that expedites paper-digital conversation can greatly reduce the time spent on charting and can also improve the timeliness that information is available to other clinicians.

Sub-goal 4.3: To support task scheduling

Patient care activities must be temporally coordinated to ensure patient care is delivered to the best interest of patients. Current systems do not provide a means to help nurses plan and schedule the tasks that they are required to perform during their shift. Instead, my investigations have found that they either mentally prioritize their tasks or externalize them on their paper notes as visual reminders. Technology is thus a good candidate to facilitate work scheduling.

7.1.5 Information

Hospital work is characterized by the need to access spatially distributed information for accomplishing work through cooperation among clinicians possessing different knowledge and expertise. As medical data constantly arises and evolves with changes to a patient's illness, medical information has been found to be tightly coupled with its context of production (Berg and Goorman 1999, Forsythe et al. 1992). Thus such information needs to be constantly (re)interpreted and (re)constructed by various clinicians so that they can utilize the information to carry out necessary treatment and care activities. My fifth design goal thus aims to support nurses' information use offered by existing artefacts for carrying out adequate patient care.

Goal 5: **To support *information* use offered by existing artefacts for patient care**

As is the case in most hospitals, while EHRs contain most of the medical information constituting a patient's health record, certain information still resides in other information artefacts, typically non-digital artefacts, such as paper documents and display boards. Information artefacts, of different form factors, in different locations, and with different information, exist to meet varying needs of multidisciplinary clinicians. To illustrate, the EHR may contain information, e.g., shift-specific nursing care information, which is also displayed in the large whiteboards inside nurses' shift change room. It thus appears that the whiteboards may be eliminated as it contains redundant information that is available in another source. However, the removal of the whiteboards could be detrimental as nurses may then be unable to acquire an overview of the ward operation with a quick glance.

7.1.6 Communication Mode

Traditionally in medical settings, information was primarily communicated through verbal, paper, and display medium (Bardram 2000, Cabitza et al. 2005, Kovalainen et al. 1998, Luff et al. 1992, Xiao et al. 2001). Advances in information technology have led to an increasing adoption of electronic health records, replacing paper-based records, to provide remote access to clinical information (Hatcher and Heetebry 2004). Thus, a variety of digital devices was designed and introduced to work places. However, current digital technologies often require considerable changes to existing work practices and thus undermining the adoption and ultimate acceptance of the deployed technologies (Mackay 1999). Therefore, I strive to design technologies providing familiar and effective communication modes to support work practices.

Goal 6: **To provide preferred *communication modes* to support work practices**

Sub-goal 6.1: To enhance familiar pen and paper interaction

With the increasing awareness of the importance of having information easily available at points of care for improved patient care, various mobile technological devices have often been introduced, e.g., personal digital assistants (PDAs), smart phones, Tablet personal computers (Tablet PCs), and computers-on-wheels (Silva et al. 2006, Tang and Carpendale 2008a, Zamarripa et al. 2007). However, these devices rarely afford an intuitive mode of interaction for accessing information at points of care (Cohen and McGee 2004, Lu et al. 2005). In fact, information entry at points of care using digital devices has been found to be heavy-weight and inefficient. Thus, paper personal artefacts are still heavily in use as immediate information lookup and as intermediate information recording tool at bedside. Such information temporarily inscribed on paper eventually has to be transposed to the digital medium through a process commonly known as charting. Yet, current charting processes are prone to errors due to the divide between the paper and a digital medium (Zamarripa et al. 2007). Therefore technologies that allow efficient transfer of information from handwritten notes on paper to digital medium could prove valuable in saving the charting time and to reduce the errors that may arise in the course of the information transfer.

Sub-goal 6.2: to facilitate information retrieval and entry through voice commands

Hands-free mobile voice technology has been shown to be useful for connecting distributed collaborators and reducing spatial movements (Chapter 6). In fact, the participants in our study ward developed a workaround by using the mobile voice device to quickly record newly-emerging and rich information while remaining on their task-at-hand. This indicates a good potential that similar technologies could provide an easy-to-use feature for clinicians to verbally retrieve information and to take verbal notes during their shift work. With advanced voice recognition software, the recorded notes may possibly be converted into digital text to further facilitate the charting process.

7.2 Technology Design

With the design goals described above, it is clear that there are many aspects of the information flow that would benefit from an investigation into what might be appropriate technology for supporting the information flow. Thus approaches to technology design abound. Several approaches will be described below and are illustrated in Figure 7.2 (from top left, clockwise). However, these approaches are by no means exhaustive of possible designs of technologies for supporting nurses' information flow. Instead, they would be good starting points for the technology design. These approaches make use of existing and augmented information artefacts preserving the desirable affordances of various information artefacts currently available on the ward, and are centered upon the distributed information sharing capability of digital technologies. From these design approaches, I will then limit myself to focus on one particular aspect and will, in the next chapter, describe the prototype and its evaluation on its roles in improving nurses' information flow whereas the others will be left for future work.

First, digital displays could replace traditional whiteboards to preserve the ability to provide overviews and awareness of current operation while allowing entry and retrieval of information at remote locations over a wired or wireless network. This technology design could prove useful because currently with traditional whiteboards, nurses would typically choose not to physically go to the designated location to compose shift reports on the whiteboards when they are busy. As a result, incoming nurses would have to look for required information through other media such as to physically look for their outgoing colleague for a verbal shift report or to look up various medical records to see if required information has been documented. Therefore, this design approach could

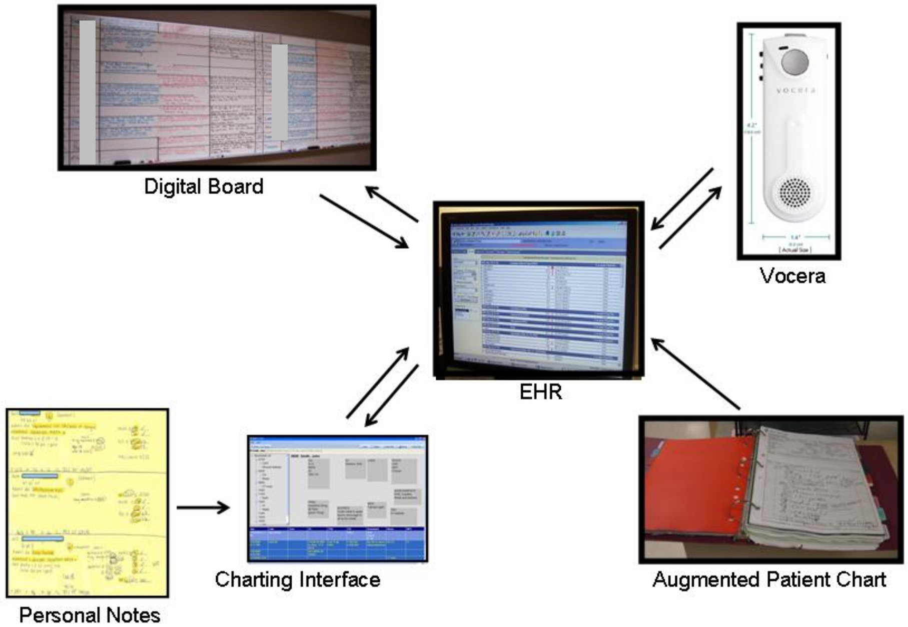


Figure 7.2 Technology design approaches for supporting information flow

considerably improve nurses' information flow such that information, specifically written shift reports, would be available in a more timely manner.

Second, technology design may also allow clinicians to make use of a mobile voice communication system similar to Vocera as a dictation device for hands-free note-taking and as an information retrieval device for accessing electronic health records through voice commands. In fact, the note-taking function has already been practised as a workaround in our study ward when nurses were too busy to write down newly emerging information (Section 6.3.2.2). Nurses used Vocera to call themselves and leave voice messages on their own Vocera so that they could retrieve them later. Thus, new technology design could provide more efficient hands-free note-taking feature to facilitate the information flow. Technology can also be designed to allow nurses to use voice commands to retrieve information from the digital records, e.g., at points of care. This voice-operated information off-loading and information retrieval capability would be particularly valuable when nurses' hands are occupied, e.g., with equipment and apparatus.

Third, digital pen and paper technology such as Anoto^{TM} technology (Anoto) could benefit information flow in the medical setting. A digital pen is equipped with a micro-camera for capturing and digitizing handwriting strokes made on a piece of digital paper which is pre-printed with specific dot patterns to allow a digital pen to also identify and store the location where the handwritings were made on the digital paper. Thus with the digital pen and paper technology, clinicians can retain the use of familiar pen and paper while the digital technology offers easy digitization of the handwritten information. This technology can be applied to patient charts so that clinicians can use a digital pen to write and annotate flexibly on a patient chart that is composed of digital paper. In this way, their handwritings will be digitized and saved to the database for sharing among distributed clinicians. Besides, clinicians no longer have to look for the physical chart when looking up the inscribed information thus solving an existing problem when the charts are being removed from their designated location (Section 3.3.5.1). However, they still need the physical digital-paper patient chart when entering information.

The final design approach to be described in this chapter also makes use of the digital pen and paper technology. Digital pen and paper can be used for preparing personal notes so that handwritten notes can be easily digitized. However, instead of saving the handwritings as digital files that retain free-form annotations and sketches as is the case for the digital-paper patient charts, this design can use handwriting recognition software to convert handwritings to digital texts which can then be readily saved to the electronic health record. However, current handwriting recognition technology still falls short in delivering perfect, and sometimes satisfactory, outcome. Therefore, an intermediate application that interfaces between the personal notes and the electronic health record will allow clinicians to edit the converted texts on the same and familiar interface as that on their personal notes and to verify the correctness of the data to be charted before saving to the electronic health record. The data verification before charting should also be enforced as a mandatory process. In this way, the integrity of information can be ensured and navigation along the hierarchical information system can also be minimized. This design could thus potentially save clinicians' time in charting as they do not need to manually enter handwritten information to the digital medium and to cumbersomely navigate the information system. It is this last design approach that integrates paper and digital charting that I will prototype and evaluate in the next chapter.

7.3 Technology and Health Care Quality

The research presented in this dissertation set out to improve the nurses' information flow through technological solutions, which could in turn help reduce the occurrence of medical errors and improve the quality of health care (Bates and Gawande 2003, Nolan 2000, Reason 2000). Thus, to resonate the Joint Commission's goal to improve healthcare quality through improving communication and information flow among caregivers, the technology design proposed in the previous section will be discussed from the perspective of health care quality.

Technology that includes large centrally-located digital displays that provide an overview of the ward operation may potentially increase clinicians' situational awareness (Xiao et al. 2001) so that they can be better prepared to deal with contingent circumstances (Bardram et al. 2006). For example, being more knowledgeable about other patients' conditions is beneficial when providing assistance in critical situations, which in turn improves the quality of patient care (Bates and Gawande 2003). Besides, replacing large whiteboards with digital displays provides an option for outgoing and incoming clinicians to compose and to retrieve shift reports digitally and thus may be able to mitigate the time spent on spatial movement to the designated locations where the physical boards are located during their busy work schedule.

Mobile voice communication devices that allow nurses to record audio notes with minimal effort at points of care can also help improve the health care quality by capturing detailed information that emerged during their shift without interfering with continual patient care. Moreover, capturing rich patient information in full details and in real time through voice commands and recording allows nurses to instantly offload the important information which can then be readily available for charting and subsequently for use by other clinicians (Bates and Gawande 2003, Nolan 2000, Reason 2000). Being able to retrieve information through voice commands at the point of care without leaving the task-at-hand could prove valuable to improved health care quality especially in situations where leaving the patient alone is not appropriate.

The proposed technology design also includes augmenting patient charts with digital capability to allow clinicians to remotely retrieve information inscribed by other clinicians. This is particularly valuable when the charts are temporarily removed from their designated location which has been quite common in our study ward. Without having to physically look for patient charts, clinicians could have more time for actual patient care.

On the other hand, current information systems require tedious log-on and navigation when accessing information whereas technological devices are reported to be problematic such as short battery life, unstable network connectivity, and inflexible inputs and form-factors. Therefore pen and paper continues to prevail to provide low-cost information access at points of care despite its limitations such as the quantity of information available on the paper artefact and the possibility that the inscribed information is not constantly updated. To address this, enhanced personal notes utilizing digital pen and paper technology offers a good potential to facilitate the efficiency of information flow by easily downloading and converting newly emerged information from paper to digital medium without manually transposing the handwritten information. Such time savings could result in improved patient care as time crunch has been reported to impede quality patient care.

The role played by handwriting conversion in our technology design raises the question of how reliable current handwriting recognition software is. In fact, such current technology is still far from being perfect. This is particularly true in situations where own symbols and random sketches are used such as in nurses’ personal notes. However, Silva et al. (2006) provided encouraging results that even only a few keywords or some initial notes in digital text would help facilitate the compilation of full medical notes. Besides, the handwriting recognition technology is expected to continue to advance.

The proposed technology design is also unlikely able to solve all the existing problem of information inconsistency among information artefacts of different media types. Our technology design, however, has the potential to improve the information exchange in medical settings by narrowing the divide between a subset of the multimedia information.

7.4 Chapter Summary

This chapter demonstrated a use of the InfoFlow Framework to generate a set of design goals for developing technology to improve nurses' information flow in our study ward. The design goals helped develop technology designs which are based upon the desirable affordances of existing and augmented information artefacts and the capability of digital technologies for distributed information access. The design approaches described in this chapter separately contribute to improving specific aspects of the information flow. Together, they could considerably improve the overall information flow. The proposed technology design was then discussed from the perspective of improving health care quality, which showed that our design has the potential to improve the information exchange in medical settings by bridging the divide between a subset of multimedia information.

To evaluate if and how the technology design proposed in this chapter can support and improve information flow, a mixed-fidelity prototype that made use of Anoto™ digital pen and paper technology to bridge the paper personal notes and the digital information system was developed and will be presented in the next chapter. A focus group study with practising nurses who evaluated the effectiveness of the prototype system in facilitating nurses' information flow practices will also be presented.

Chapter 8. Paper and Digital Integrated Charting and Evaluation

This chapter presents a prototype of a technological approach that was part of the technology design presented in the previous chapter. The prototyped technological approach was designed for bridging paper personal notes and digital charting as described in Section 7.2. The prototype was built upon identified discord between the way nurses use pen and paper to record notes and observations taken at the point of care, vs. how they feed this information into the electronic record. The focus on the flow of information from a nurse into the EHR is a crucial factor in overall nurses' effective collaboration and coordination. If the nurse can enter primary notes and readings during patient contact, the nurse/patient face to face interaction is naturally facilitated (i.e., note taking will not interfere). If the information is entered into the EHR in a correct, complete and timely way, the way other nurses on the current or on a later shift can exploit this information (usually asynchronously) is also improved. Of course, the long-term archival record is itself an information source that is used by many others, be it administrators, doctors, and so on. Again correctness, completeness and timeliness are critical.

Given this context, my prototype allows nurses to maintain their familiar and efficient practice of personalized information recording on a paper-like interface while integrating their paper inscriptions and direct input into the digital hospital information system. I believe such paper and digital integrated charting has the potential to improve not only charting efficiency, but will also increase information timeliness by making that information immediately available to other clinicians. I conducted a focus group study around the prototype as a preliminary step to evaluate its effectiveness in facilitating nurses' information flow practices.

I will first describe the integrated charting concept. I then describe the focus group study I conducted to evaluate the technology prototype. This is followed by the findings. Finally, I summarize the lessons learned as adjusted and refined design guidelines for building technologies to support nurses' information flow practices.

In summary, this chapter presents:

- The design and prototyping of a paper and digital integrated charting concept, designed to support informal use of paper personal artefacts as an integral part of the official documentation process.
- The study and analysis of focus group feedback from nurses to evaluate the effectiveness of this integrated charting approach.
- A detailed set of design guidelines for future technology development.

8.1 Iterative Design

My design was initially generated from the design goals established in the previous chapter and evolved iteratively in response to feedback received from the participants through discussions and presentations. To illustrate iterative nature of the design process, the baseline study presented in Chapter 3 identified that extracting information from the EHR and writing personal notes on paper was time-consuming and tedious. Thus, I first intended to replace this manual transcription practice with a computer interface which would allow nurses to drag and drop required information from the EHR directly onto a personal notes template and provide features to augment important information such as highlighting or using different colors. These personal notes can then be printed, used as immediate information source, and as an opportune notepad adding information as it is acquired during their shift. However, subsequent informal discussion with the nurses indicated that the manual handwriting process at the beginning of a shift was crucial for building a solid mental model of the agenda for their shift, which is analogous to the findings in Ash et al. (2004). Similarly, feedback was continuously fed into the design process leading to re-design, re-thinking, and validation of different aspects of the design. Thus, my design aims to:

- support nurses' current information flow practices,
- build upon the affordance of paper,
- use the advantages of EHR to provide real-time availability of consistent information to distributed clinicians.

8.2 Paper and Digital Integrated Charting Overview

In my Paper and Digital Integrated Charting (PDIC) approach, the EHR exists in full functionality, uncompromised and, if desired or if necessitated by circumstance, can be used and interacted with as before. In addition, information gathered from the EHR can be organized with digital pen and paper as best suits personal work practices. This digital paper personal information artefact can be used through the shift just as previous personal paper notes were used, recording work done and collecting pertinent information as it

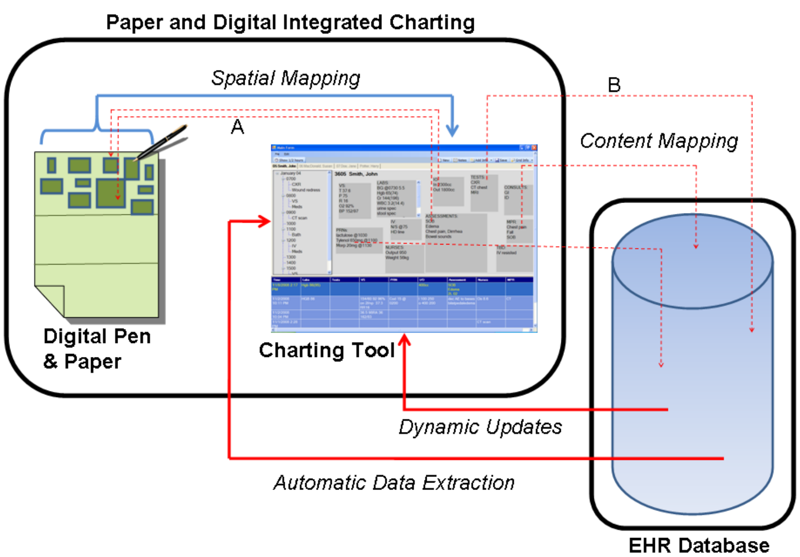


Figure 8.1 Design scheme of Paper and Digital Integrated Charting

arises. A charting interface facilitates the recording of the information generated during the shift into the EHR.

A schematic design of the approach as integrated with the EHR is shown in Figure 8.1. It adds two parts to the EHR information system: digital pen and paper technology (Figure 8.1, left and Figure 8.2), to allow nurses to use tangible pen and paper as they did previously, and a computer application, Charting Tool (Figure 8.1, center and Figure 8.4), for creating digital paper templates and converting handwritten notes into digital text (Figure 8.4, top). The dotted lines (A and B) in Figure 8.1 indicate the mappings between these components and are described below.

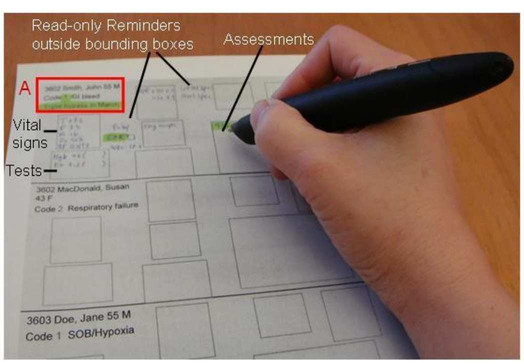
8.3 Paper and Digital Integrated Charting Components

8.3.1 Digital Paper and Pen

The PDIC makes use of the Anoto™ digital pen and paper technology. Regular paper is printed with Anoto dot patterns which when combined with a pen that contains a camera provides digital functionality. The patterns consist of numerous small black dots that are digitally legible and form an innocuous background that does not interfere with normal use for writing and diagrams. The existence of many patterns can make individual pages uniquely identifiable. The digital pen (Figure 8.2) contains a digital camera that captures all the markings made on digital paper. The dot pattern on each digital paper indicates the exact position of markings made by a digital pen on the paper. This location-sensitive capability of the digital paper supports creation of distinct regions that can be identified visually for organizing information and computationally when interfacing with the EHR. It is also possible to discriminate between information written in a region or between regions. Thus all notes including information on the exact position the markings on the paper are digitized by and stored in the pen. This information can be downloaded to a computer immediately via Bluetooth technology, or at any point in time using the pen docking station (Figure 8.2b).

8.3.1.1 Creating personal notes templates

Individual nurses can customize digital paper for their shift by using the charting interface (Figure 8.4, top) to create and save a template that specifies the information types and their layout. To create a template, an information type, e.g., vital signs, is chosen and a box that bounds the region that will contain this information type appears in the charting interface. It can then be moved and resized as desired. This method provides flexibility for nurses to each has their own type of personal notes and binds the regions on the digital paper with the specified information type. Other information types can be added in the same way until the template layout is satisfactory. Thus the charting interface can be used for creating any number of information layouts. Based on findings that nurses used a layout for all patients and preferred all their patients' information displayed on a single page (Tang and Carpendale 2007a), once a template is created nurses can specify the number of patients and obtain a digital paper that uses their template sized appropriately for their number of patients. For example, Figure 8.3 shows a template created on the charting interface (a), and two personal notes for 4 (b) and 5 (c) patients using the same template for different number of patients. This reflects the way nurses dynamically adjust their personal notes in practice.

(a)


(b)


Figure 8.2 a) Personal notes template printed in digital paper with customized layout of bounding boxes and pre-printed static information such as patient name, age, and gender (b) A digital pen placed in a docking station

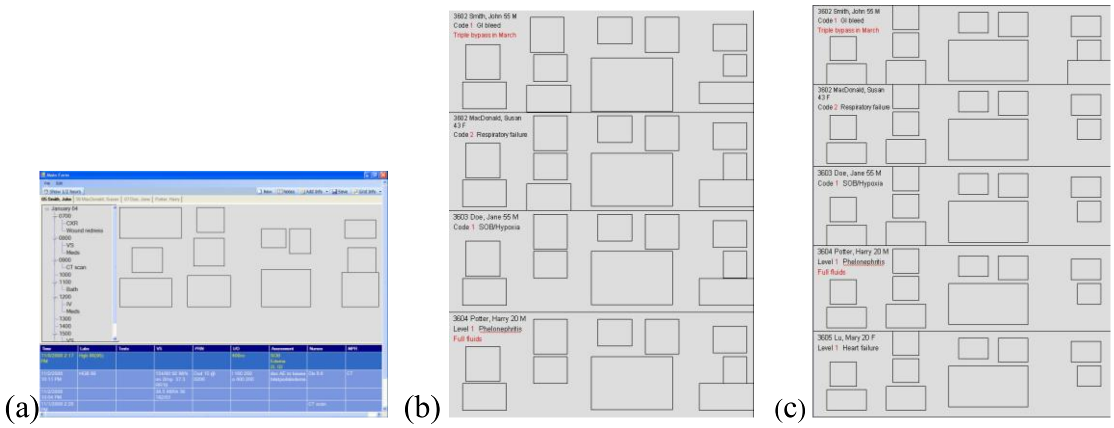


Figure 8.3 (a) Personal notes template created on Charting Interface (b & c) Personal notes printed for 4 and 5 patients respectively for illustration

8.3.1.2 Using digital-paper personal notes

At the beginning of a shift, nurses print their personal notes based on their template on a digital paper (Figure 8.3, b & c). Patients' static information such as demographics and medical history can be printed with the template (Figure 8.2a, A). Nurses can then use their digital personal notes with their digital pen. If desired they can still highlight important notes with regular highlighters (Figure 8.2a), as has been common practice. Thus these digital personal notes can be used as before to facilitate nurses' work both as a bed-side information look-up, and for recording newly emerging information. For example, as before nurses can record vital signs in the vital signs region.

Nurses' normal practice also includes notes used for references or for personal use that is not intended to be charted. For this, PDIC provides two alternatives: 1) spaces outside the bounding boxes are not charted by default, or 2) bounding boxes can be designated for this specific purpose. Handwritten notes placed in region thus specified will be discarded and will not be converted into digital text for charting, whereas handwriting in the other bounding boxes will be processed and converted into digital characters for charting.

8.3.2 Charting Tool

The Charting Tool is the software interface between the EHR and the digital paper and pen. It consists of three components (Figure 8.4):

- a single charting interface for editing and charting (top)
- a quick reference for viewing up-to-date clinical information (bottom)
- a task timeline to support planning of the shift work (left)

To allow a nurse to focus on one patient at a time, the interface displays information for one specific patient, switching between patients is easy with the tab design (top row).

8.3.2.1 Charting Interface

The same charting interface is used by nurses to create personalized digital paper notes and to transfer handwritten notes captured with the digital pen to a computer. Connection between the digital pen and EHR is done either via the pen docking station or continually via Bluetooth during nurses' shift. However, to maintain the integrity of the EHR, the downloaded information will not be processed until the charting interface is used to verify it. The downloaded notes are converted by handwriting recognition software, into digital characters which are displayed in bounding boxes corresponding to the defined regions on the digital paper. In the charting interface these notes can be edited if necessary. Nurses are required to verify and confirm the correctness of the information to be charted before saving into the EHR. Once confirmed, the charting interface bounding boxes are mapped to the corresponding fields in the EHR database (Figure 8.1, B). Through this charting interface, nurses do not have to navigate through the EHR and instead of manually entering the data for charting they simply verify and edit, potentially saving a lot of nurses' time. The charting interface also allows nurses to chart spontaneous but important information from sources other than their personal notes. This can be added to appropriate bounding boxes or entered into a new clear box. Information entered in this manner also requires verification.

Provision for resizing and relocating the bounding boxes, and for dragging and dropping text between bounding boxes allows nurses to easily move information to the correct bounding box. The interface is also customizable and extensible for other less-frequently used information types in order to meet varying needs of patients. For example, if blood work is not already in the template, nurses can dynamically add a bounding box labelled blood work. Nurses can then type in information pertinent to blood work, and this will be saved to the corresponding field in the EHR along with other information.

8.3.2.2 Quick Reference

The quick reference provides an at-a-glance overview of the EHR as pertains to the patient in view with most recent information first. This enhances information retrieval from the EHR and can also be used to countercheck if specific data has been charted. New information added to the EHR via the charting interface will be instantly displayed and highlighted in the top row of the quick reference. This quick reference can also be

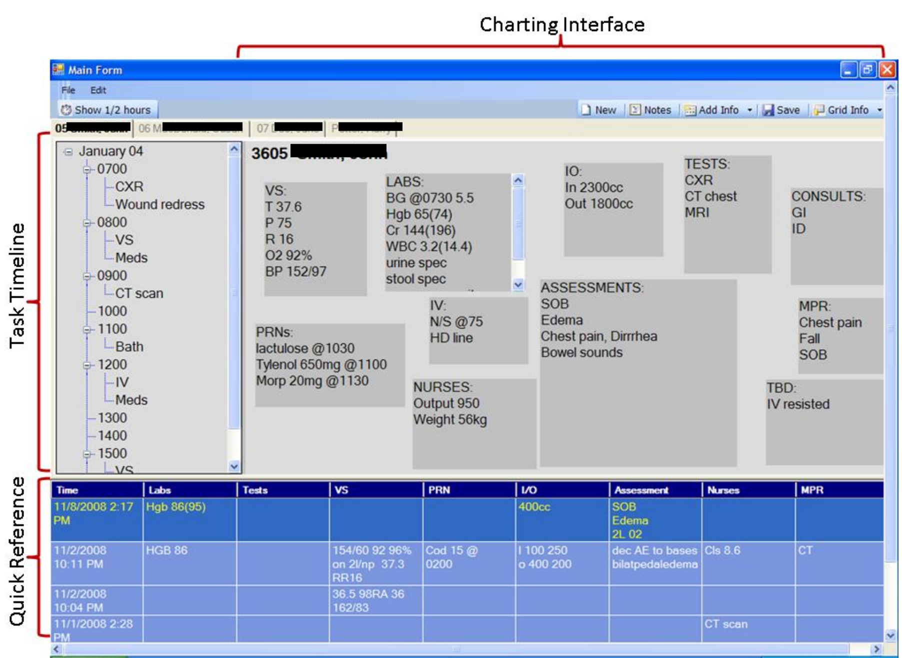


Figure 8.4 The charting tool consists of a charting interface, a task timeline, and a quick reference to medical records (patient names are masked)

customized in that rows can be highlighted if desired and the columns displayed can be customized for specific types of information.

8.3.2.3 Task Timeline

On the left hand side of the charting tool is a timeline of tasks to be performed for the currently selected patient that is initially based on time-based information such as medication at certain time intervals that can be automatically extracted from the EHR. This timeline provides an optional planning tool for clinicians to organize their shift work, can be used as a quick overview of shift work, and as a reminder and to-do list. Nurses can also dynamically adjust the timeline (i.e., add, edit, remove, move tasks) in response to changes in their patients' needs and their own temporal flexibility in the progress of their shift work (Reddy et al. 2006). In addition, it can also aid reporting to e.g., a charge nurse or an incoming colleague, as it displays the tasks that were planned and/or achieved.

8.4 The Study

To evaluate the Paper and Digital Integrated Charting, I prototyped the basic concepts and ran focus groups with participants from our original study ward.

8.4.1 Participants

Focus group participants were nine registered nurses and three nursing students. They all were experienced in preparing and using paper personal notes for their shift work. Because the participants were the targeted end-users of the technology, they were highly motivated to offer their practical experience and expectations of the technology. Six focus groups were conducted in total. Data from one group was not used because participants opted out of key portions of the focus group protocol. The participation in the focus groups was negotiated around existing nurses' schedules. These groups were planned for times when two or more people agreed to participate. The final composition of the focus groups ranged from 1 to 5 participants (5, 3, 2, 1, 1) due to unexpected illnesses and family emergencies.

8.4.2 Method and Materials

Each focus group lasted about an hour and the participants engaged in the following activities.

1. Creating an individual template. Each participant drew on paper the spatial layout of their own paper personal notes, labelling the respective types of information such as medications and assessments. Stationery such as pens, markers and highlighters of different colors were provided. Participants were encouraged to create the template as close as possible to the personal notes they created and used in practice. This activity took less than five minutes.

2. Creating a collaborative template. Participants worked as a group to discuss and design a template for personal notes that was acceptable to all members of the group using either a large flip-chart or a Smart board (Figure 8.5a). This group template was

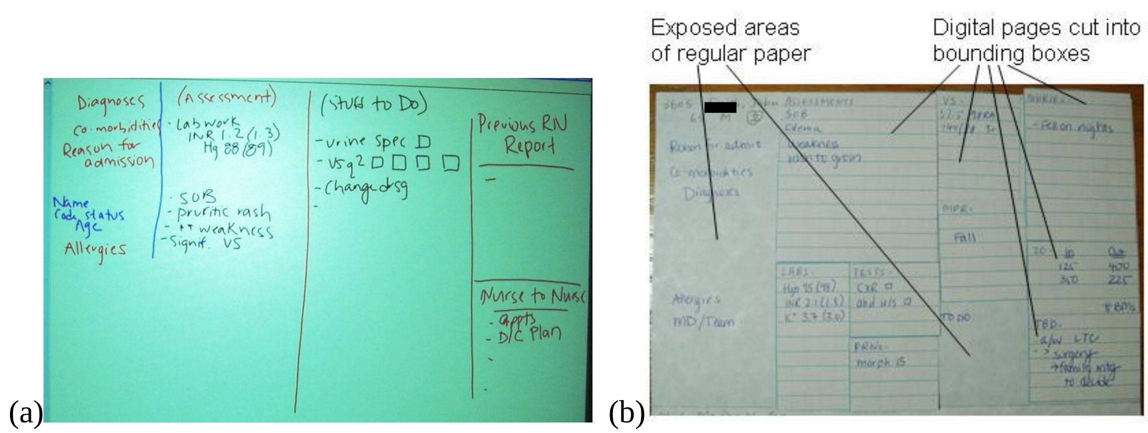


Figure 8.5 a) Collaborative template created on Smart Board (b) Corresponding paper prototype created by gluing snippets of (lined) digital paper on a piece of regular paper (plain grey)

needed for use in the next activity. Single participants simply used their own template.

3. Prototyping personal notes. Pages from Adapx™ Digital Journalx, which were lined and printed with Anoto™ dot pattern (Figure 8.5b), were used. These pages have the same property that PDIC is based on. Each page is identifiable due to its dot pattern. Participants then cut pages to create required regions and glued them on a piece of regular paper (Figure 8.5b) to match the layout of the collaborative template from activity 2 (Figure 8.5a). Thus notes and handwriting inside each region created from digital paper will be captured, digitized and identified for a specific kind of information by a digital pen. Exposed areas of the regular paper could be used for information that is not required to be charted.

Minor inconsistencies were found in the information types predefined in the charting interface and those used in the collaborative template created in Activities 2 and 3. For example, separate regions were provided for laboratory work and tests whereas some collaborative templates contained only a combined "labs and tests" information type. Therefore, participants had to slightly adjust the layout of the bounding boxes on the constructed digital paper notes. These constructed digital paper notes were in turn used in the next activity

4. Exploring the PDIC prototype. The researcher explained how the boxes and areas outside the boxes on constructed digital paper notes interfaced with the charting tool. The charting tool was displayed on a Smart board mounted to the wall (Figure 8.6) to offer a clear view to all the participants and to trigger discussions incorporating their own practical experience and expectation (Wilson et al. 2006). Participants were frequently encouraged to discuss and comment on their experiences and expectations of the technology to better support their work. How the digital pen and paper work was also explained such as the dot pattern imprinted on the digital paper, the embedded camera in the digital pen, and why the exact position of markings made on digital paper was known.

Participants then used a digital pen to write on their paper note (Figure 8.5b), pretending that they were preparing and using it as their personal notes in a work shift. They were encouraged to write as they would normally do. Information sheets which contained fabricated medical information, previously compiled with the help of a registered nurse, were provided for participants to prepare the digital personal notes. However, all participants wrote down information from their own experience without consulting the information sheets.

The handwritten data was then downloaded via the pen docking station (Figure 8.2b) connected to a computer. The researcher triggered the use of handwriting analysis software to convert the handwritten data into digital text and explained how this happened (i.e. Wizard of Oz technique) whereas this would be automatically done in a fully-implemented system. Participants could then click the 'Notes' button on the charting tool and see the text converted from their handwriting that was inside the bounding boxes on their digital paper notes. Participants were encouraged to edit and add more detailed information to the displayed text to the point that it was appropriate for charting. They then saved the information after verifying its correctness on the

Figure 8.6 Participants exploring the integrated charting system displayed on a smartboard

verification screen. Participants were encouraged to explore and comment on all aspects of the charting tool such as the timeline and the quick reference update.

8.5 Findings

The main goal of the study was to identify strengths and weaknesses of the design of the Paper and Digital Integrated Charting, in particular whether it can facilitate or impede nurses' work practices around their information flow, and to gather suggestions for improving the system design. The study employed a combination of varying-fidelity methods instead of a full-fledged system to demonstrate the design concepts and to actively draw the participants into the design dialog. The first three activities, i.e. to draw a personal template, to sketch a collaborative template and to craft a paper prototype of personal notes using digital paper snippets, were conducted to progressively prepare for the last activity which was the focus of the study. Therefore, I briefly highlight the findings from the preparatory activities and then concentrate on the findings of the last activity to explore the PDIC prototype.

8.5.1 Highlights of Preparatory Activities

8.5.1.1 Create an individual template

Although the individual templates appeared different, they all contained a consistent set of information: static information (room number, patient name, age, medical history, doctor's name, resuscitation level, allergy, special diet, diagnosis), and dynamic information (vital signs, assessments, I/Os, IV, tests, labs, blood work, medication, previous shift report, and new orders). All the participants confirmed that they created and used paper personal notes for their work.

P1: *"… I would never give up my piece of paper. Literally if I lose it, I'd spend like 40 minutes trying to find it. I'll go through every garbage bin 'cause it's like your lifeline. I don't know what to do with myself if I don't have it."*

P4: *"Because our entire day works on that piece of paper, everything we do, when we need reports, we wouldn't go to the computer. It's all on that [the personal notes]."*

P6: *"I don't know what to do whenever I lose it [the personal notes]."*

8.5.1.2 Create a Collaborative template

Three focus groups conducted this collaborative activity. Two groups created a new collaborative template based on discussion of the participants. One group selected one of the participants' personal templates as their group template after comparing and contrasting their personal templates and finding that the spatial layout was the only difference among them. Moreover, many participants said that they made changes to their personal templates in terms of both the layout and the information content from time to time when their experience increased and when their patients' needs differed. The activities and discussions around designing a collaborative template indicated that a default but adjustable template could be useful.

8.5.1.3 Prototyping personal notes

All groups constructed their digital paper notes using snippets of digital paper glued on a regular paper. Three groups conducted this activity based on their collaborative template and the other two were based on the participant's personal template.

8.5.2 Exploring the Paper and Digital Integrated Charting Prototype

Participants' responses towards the technology design were mostly positive and encouraging. They were particularly delighted that the design was based on pen and paper interaction. They saw great potential and value of the system in facilitating their work. Several participants asked when the technology would be available for use in practice. Yet, they also identified weaknesses of the system and made suggestions for improving the technology design.

8.5.2.1 Strengths

Pen and paper. Participants' reliance on their paper personal notes during shift work was in evidence as they referred to personal notes as their 'lifeline' and 'my entire day works on [my personal notes]'. They perceived great benefits in retaining the use of the familiar pen and paper and were excited to see that their handwriting could be converted to digital text without requiring manual re-typing at a computer. They voiced hope that this could considerably improve their charting efficiency as they would only need to edit or add to the converted information.

Single-interface charting. Participants found the ability to chart multiple information types with the same interface useful. They also found the flexibility to dynamically extend the interface to include other kinds of information for charting convenient. They expected that charting would become more efficient and more comprehensive because current tedious and time-consuming navigation of the hierarchical EHR could be minimized. Making current information pertaining to one patient visible on the same interface provided an overview and a more comprehensive picture of patient's condition that could help more easily organize and document different kinds of information gathered during the shift. They also commented about huge time savings to benefit both actual nursing care and hospital finance by paying less overtime work.

'Personal' information space. Some participants wrote everything inside the digital-paper bounding boxes on the constructed digital personal notes whereas others used the space on the regular paper for information that was not meant for charting (Figure 8.5b). The former pointed out the need for a 'personal' information space on their personal notes when they saw the converted text of their personal notes displayed in the charting interface included also their 'personal' information. They explained that this kind of information was vital for accomplishing their nursing work, regardless if it is information extracted from documented sources to serve as reference information, or their own personal opinions towards a patient, e.g., as a reminder of specific ways to deal with the patient, or just some scribbles for catharsis to relieve their stress. In short, all the participants agreed that personal notes should provide 'personal' information spaces for writing down information that will not be charted.

Focus on new information. Participants liked the design that previously charted information is not displayed in the charting interface so that they can always focus on newly emerged information. This is because the charted information would still be readily available in the quick reference table below. One participant suggested including an option for displaying the charted information in the charting interface as long as it was easy to differentiate between the old and new information such as using different color or different font style.

Quick reference facilitates information retrieval. All the participants regarded the quick reference that offered an at-a-glance view of the archived medical information useful. They found it convenient to look up medical records without having to go through the hierarchical EHR. They also found the dynamic updates in the quick reference table when new information was saved to the EHR helpful in that they could be more aware of up-to-date patient information.

P1: *"I like it [quick reference] because… sometimes you don't get a good report from the previous nurse, then you can scroll back to see what the nights [nurse in night shift] think. I wish we had something like this… For example, if a patient fell, the nights tells the days and the days tells the evenings, but when nobody tells anybody anything, you forget that this person may fall. But if there's this thing [quick reference], I can just go back to see what happened and like what's the plan 3 days ago."*

P12: *"I really like that I don't have to go to different places to look for new things for the patients and it's all here in the blue table [the quick reference table]. I like that!"*

Timeline useful to new nurses. Most experienced nurses did not find the task timeline useful for planning and organizing their shift work.

P11 (an experienced nurse): *"nursing uses flexible process…constantly shifting…no way to plan like this… If you're going to spend time on this, you'll never get to patient care".*

However, student nurses liked the timeline. They perceived it a useful tool to help them focus on their work and to allow them to visualize their work schedule and work load. Many experienced nurses recalled that they also manually created similar timelines for planning their work when they were new. But they had abandoned this practice as they became more experienced with their nursing duties and were more used to the dynamic and flexible nursing processes. Therefore, they believed that the timeline would be a valuable tool for training and educating novice nurses.

8.5.2.2 Weaknesses and Concerns

Liability issues. Participants were particularly concerned about their liability for the technology in case they lost their digital pen. Since a digital pen is much more costly than a regular pen which nurses do not worry about losing, participants were worried if they had to be financially responsible for replacement. This led to active discussions on ways to prevent losing the digital pen. Suggestions included carrying it around their neck with a lanyard but they were then worried about the number of gadgets that they had to carry with them. They were also concerned about the technology's costs, durability and environmental issues (e.g., recyclability of digital paper).

Handwriting recognition. The participants did not express negativity towards the handwriting conversion because their handwriting was generally converted quite well in the study. However as expected, many participants were concerned with the general quality of handwriting recognition. They were also worried about their handwritten symbols and abbreviations (e.g., SOB for short of breath and CXR for chest x-ray) and whether they could be properly transcribed.

Embedded charting. Participants criticized the design in that it did not facilitate 'flow sheet charting' which is an embedded structure in the EHR. They are required to access this by navigating the information system in order to chart by "point and click" a checklist of information categories in the flow sheet. They suggested having a button on the charting interface that linked with the flow sheet so that they could directly access it without navigating the information system. The researcher proposed using digital-paper flow sheet printed with checkboxes so that charting on flow sheets can be done anywhere and the checked information can be easily transferred to the EHR. This alternative was well received especially by experienced nurses who prefer paper artefacts to digital medium. But younger nurses found a single-mouse-click link to the digital flow sheet more beneficial.

8.5.2.3 Suggestions

Extending the potential of digital pen and paper technology. In view of the potential of digital pen and paper, participants suggested designing the personal notes to include areas for other documentation and reporting purposes in addition to EHR charting. As currently, nurses have to write or verbally report the same information multiple times in different places such as in patient charts, verbal shift reports and large whiteboards, requiring much mobility and redundancy of effort. Therefore, they considered it a great value if they only needed to write once on their personal notes and the information would be saved or displayed (with or without converting to digital text) instantly in different media. For example, participants could write a shift report on their personal notes for relevant clinicians such as their incoming colleague or charge nurse to retrieve at a computer. Participants perceived significant savings in time and mobility when they no longer needed to look for people in order to give or receive reports.

Support both customizable and customized interfaces. Many participants resented that they always had to navigate to their last visited screen every time they logged on the EHR. They were also frustrated that the current EHR did not allow them to keep their customized views of information which would be automatically reverted to the default view when they logged off the system. They estimated that this practice of logging on and off the EHR took place 50 to 100 times per shift. Thus they emphasized it is imperative that our design allows them to continually use their customized views and to display their last visited screen upon logging on. They also expected that these features would greatly improve their work efficiency.

8.6 Discussion

Integrating the effective aspects of current work practices with the advantages of the EHR is the goal of the Paper and Digital Integrating Charting. Thus this research commenced with observational studies to form a thorough understanding of current work practices. The evidence from our field studies indicated that while nurses' use of pen and paper held many advantages, it was in conflict with the hospitals' goal of the consistency of the EHR. This led us to design technology using digital pen and paper so that handwritten notes can be easily digitized, thus working towards the goal of integrating the best of both directions.

The focus group study I conducted using a prototype developed with mixed-method approach provided encouraging feedback. For example, *"This is really quite exciting and I know there're glitches that are not working as well as we'd like. But we're moving towards the right direction"* (P11). While weaknesses were identified and concerns were expressed, the feedback gathered indicated potential of the PDIC and gathered together provides the following set of refined guidelines.

Support flexibility and personalization. Participants in general were most pleased by the potential for both supporting their current work needs and having the flexibility to have support of changing work practices.

- The use of flexible templates, as exemplified by the use of bounding boxes to create identifiable and recognizable interface components that can be resized and reorganized to match personal preferences provides both consistency for the computational interface and individuality for personal use.
- Familiarity with interfaces can facilitate work (Kidd 1994). Thus it is important that the customized interfaces can be saved for ongoing and future use.

Facilitate information entry and retrieval. Participants discussed several aspects about current systems that were time-consuming from disseminating information to multiple media to repeated clicking in the EHR. They were hopeful that PDIC would provide considerable time savings.

- Providing navigation that is based on recognizable interface components which have established system mappings has considerable potential for streamlining information updating and retrieval.
- When possible embed required information structures (e.g., flow sheet, multidisciplinary report) within an integrated interface.

Provide an overview. Participants liked being able to see the information gathered from their digital personal notes in conjunction with the timeline and quick reference. They particularly appreciated the quick reference and its instant update on information verification and entry.

- Combining several information representations in a customizable interface avoids problems with fragmented information that has been scattered over different places and has been found to impede the building of mental model (Ash et al. 2004).
- Viewing a comprehensive set of information can provide feedback on what has been done and still needs to be done thus greatly facilitating the charting process and its quality.
- Enriching the information presentation, such as including the timeline which was found to help novice nurses plan, organize and focus on their work, may further enhance the learning outcome and the work efficiency.

Support 'personal' information use. Personal notes, as the participants indicated, are created and used by their owner so are inherently personal and traditionally contain both archival and non-archival information that is only intended for personal use. However, with the use of digital pen and paper, the real 'personal' information would run the risk of being publicized over the digital medium.

- Some information spaces should be assigned strictly for ‘personal’ use only without leaving any digital trace. Otherwise, the technology would fail to support individual needs and may experience adoption resistance.

Safeguard the accuracy of information. This factor is always a concern for healthcare systems and our nurse participants are no exceptions. Many discussions and comments focused on this topic primarily in three ways.

- The system must always instigate a mandatory, yet lightweight, verification safeguard before information is saved to the database to uphold the integrity of information accessible by distributed clinicians.

- The system should provide an option of keeping a cache of personal notes information that can be retrieved by its owner. This will be useful in case the frontline information artefact needs to be reproduced.

- The reliability of handwriting recognition is a justifiable concern. However, the use of mandatory verification makes this feasible and with advances in handwriting recognition technology, the captured, digitized handwriting can be converted into digital text with increasing accuracy, narrowing the divide between paper and digital medium.

Support system dispersal. The participants noted, and is confirmed in previous studies, that they both retrieve and disseminate information from/to multiple sources. These rich varieties of information artefacts in medical settings facilitate various groups of clinicians to accomplish many different goals (Bardram and Bossen 2005a). Thus it is not uncommon that the same information has to be inputted in multiple media. This practice undoubtedly cost time and effort.

- An integrated charting system that is linked with other information artefacts and displays could minimize redundancy of effort (Cabitza et al. 2005) and to provide information in multiple modals and representations (Reddy et al. 2001). This in turn will benefit patient care.

8.7 Chapter Summary

From the technology design presented in Chapter 7, I have chosen to prototype and evaluate the Paper and Digital Integrated Charting approach that offers:

- manual transposing of information from multimedia sources to a digital paper notes for building a mental model and planning of the shift work,
- the ability for individual nurses to customize their digital personal notes for facilitating information retrieval,
- portable, flexible and low-cost use of digital paper notes to support bedside information access and note-taking,
- easy transfer of information from digital paper notes to the EHR to provide timely, low-cost and continuous information flow,
- the use of personal notes as information basis for reporting in non-digital media such as in verbal shift reports,
- a quick reference to archived medical information, and
- a timeline for visually planning work.

Through focus groups of practising nurses, I studied this technology and obtained valuable feedback on the benefits they perceived and well-articulated suggestions for improving the system. Together, they helped refine the set of design guidelines, summarized as follows, that other researchers and designers may find useful in their specific settings.

- Support flexibility and personalization
- Facilitate information entry and retrieval
- Provide an overview
- Support ‘personal’ information use

- Safeguard the accuracy of information
- Support system dispersal

The next chapter will conclude this dissertation by first revisiting the research goals. The contributions of this research will then be discussed, followed by the future work that may be extended from this research.

Chapter 9. Conclusion

Through a series of careful observational field studies, this research expanded the understanding of the work practices used during nurses' information flow. These findings were then integrated with relevant literature to create the information flow framework. This framework has been used to describe current work practices, to assess the potential benefits and problems of newly deployed technology, and to inform the design of new technologies. The approach to research, starting from an in-depth understanding and moving towards the design of technologies, is intended to provide a more seamless and less obtrusive fit of technology within the working environment.

This chapter concludes this dissertation and discusses its research contributions. First, the research motivation and problems set out in Chapter 1 are revisited and the progress that was made towards these goals is discussed. Second, the contributions that this research has made to the fields of HCI, CSCW and healthcare services are discussed. Finally, directions for future research that could further the ideas developed in this dissertation are presented.

9.1 Research Goals and Summary

The central research hypothesis of this dissertation is that studying nurses' information flow practices in situ can better inform and facilitate the design and development of technology for enhancing information flow and work practices. This hypothesis was investigated through the following goals:

Goal 1: to acquire a thorough understanding of the basic information flow practices during nurses' shift change.

Goal 2: to understand the impact of technology deployment on nurses' information flow.

Goal 3: to explore the possibility of formulating a framework that can be used to guide the assessment of technologies and the generation of technology designs.

Goal 4: to demonstrate the applicability of the framework for assessing the impact of newly deployed technology on information flow.

Goal 5: to further demonstrate the utility of the framework for generating new technological directions.

Goal 6: to prototype and evaluate a technological approach for supporting nurses' information flow and using this experience to refine the design guidelines for similar systems.

Each of these research goals has been successfully reached and is demonstrated in the previous chapters. Moreover, the cumulative activities undertaken to achieve these goals have led to a more generalized set of design guidelines that could be useful to other researchers to design and develop technologies for supporting information flow in hospital settings.

9.2 Contributions

This research builds on previous research from the fields of HCI, CSCW and healthcare services. It contributes additional knowledge and practices to these fields. There are six main contributions from this research, all of which deepen our understanding of nurses' information flow in the mobile and dynamic hospital setting, and which in turn helps us understand how to support their activities through technologies.

9.2.1 Identifying Basic Information Flow Dynamics and Practices during Nurses' Shift Change

By reviewing past literature and performing a new observational field study, this research has identified important work practices as they were used for information flow in the specific context of nursing shift change (Chapter 3). It revealed several important aspects of work practices that were not identified in previous literature. For example, previous literature generally regarded information flow during shift change as a linear process of outgoing personnel first preparing information and then "handing off" to incoming personnel. However, the observation revealed the occurrence of a pair of parallel processes, namely information disassembly by outgoing personnel and information assembly by incoming personnel, both of which involve a variety of distributed information media within the exchange, that is, shift change. This study also identified nuanced interaction between personal and common information spaces, and the vital role of personal information space, which was typically externalized as paper artefacts, in facilitating information flow.

Identifying existing practices is important for two reasons. First, it can help us identify the beneficial aspects of existing information media and practices that should be preserved in the new technology design so that people can retain these familiar practices and focus on the task-at-hand rather than on learning completely new technology or interaction. Second, it helps to understand the nuanced interaction between the common information spaces and the personal information space that can help inform the design for preserving and managing their use and ownership. For example, understanding the importance of information customization for achieving work helps us preserve this particular feature when designing technologies.

9.2.2 Identifying Impact of Mobile Technology on Information Flow

By performing an in-depth observational study to investigate the deployment of a mobile information technology (computer-on-wheels) at two different time frames, this research identified important factors in terms of physical, technical, social, health and organizational aspects that explained the adoption, or non-adoption, of the new technology. The research further compared the mobile technology with the "old-fashioned" paper artefacts that are currently relied upon as information resource at points of care (Section 4.4.2). It revealed that the mobile technology failed to provide the same kind of affordances offered by paper artefacts in support of nurses' information flow practices during their shift work. Therefore, despite the availability of the mobile technology, this research revealed nurses' persistent use of paper artefacts as their:

- work plan to provide an overview of tasks to perform in the shift,
- bedside information source through customized information layout and augmentation,
- opportune notepad for quickly scribbling new data that emerges during a shift, and
- information basis for reporting newly emerged information that is important for the continuity of patient care across shifts and disciplines.

The insights gained from this investigation helped point to new design directions to encompass pen and paper interactions in technological design to facilitate the information flow.

9.2.3 Developing a Conceptual Framework for Nurses' Information Flow

Based on our own study presented in Chapter 3 and a distilment of previous literature on information flow and shift change, this research has developed the InfoFlow Framework that integrates current knowledge to provide a coherent description of nurses' information flow practices. This framework has also be shown to be useful as a tool which can aid in assessing current technology use (Chapter 6), and can prove useful in informing the design of the new technologies (Chapter 7).

The InfoFlow Framework consists of six essential components of information flow during shift change: information, personnel, artefact, spatiality, temporality, and communication mode. However, these factors are not exhaustive; other factors such as organizational mandate and social structure may also impact the information flow and should therefore be considered accordingly. While the framework was primarily designed for studying information flow during shift change, it also allows researchers to acquire a thorough understanding of the nurses' information flow. This is because information flow during shift change is an integral part of the overall continual flow of information and the studies conducted in this research spanned across both regular shift periods and shift changes. Besides, the framework allows researchers to flexibly re-configure the factors for studying the information flow and identifying areas for improvements in their specific setting. For example, we can use the framework to map out the flow of information in terms of the information content, or in terms of the participants or in terms of the artefacts through which the information is generated and communicated. The mapping then offers a concrete basis for further analysis to identify problem areas for improvements. This led to our own usage of the framework and thus to following two contributions.

9.2.4 Demonstrating Evaluative Role of the InfoFlow Framework

The InfoFlow Framework was successfully used to guide the evaluation of a newly deployed mobile communication technology, Vocera (Chapter 6). The research first identified a primary set of frequently-used communication strategies in our studies, each of which was associated with a framework factor. These communication strategies are:

- Choosing appropriate *artefacts* for information flow,
- Choosing an appropriate *communication medium*,
- Identifying and locating *personnel* to communicate,
- Off-loading *information* to the intended recipient,
- Minimizing *spatial* movements, and

- *Prioritizing* and *scheduling* activities.

These strategies were then used to assess the impact of the new technology on nurses' information flow. The investigation indicated clear benefits and great potential of the technology in supporting the time-critical and dynamic medical work and proposed several design guidelines to influence the (re)design of similar technologies to further improve the information flow.

9.2.5 Demonstrating Generative Role of the InfoFlow Framework

The InfoFlow Framework was also used to generate a set of design goals (Chapter 7) which in turn were used to develop new technology design (Chapter 8). The design goals were based on the importance of supporting work practices that nurses have established and adjusted through their practical experience on the job. These practices have been identified in the field studies presented in Chapters 3, 4 and 6. Based on the InfoFlow Framework, I described the useful characteristics of nurses' information flow and important work practices that are crucial to their work accomplishment around the framework factors for the generation of the design goals as follows:

- To support *personnel*'s actual work practices,
- To preserve existing *artefacts*' desirable affordances for interaction,
- To enhance accessibility of *spatially* distributed information,
- To facilitate *timely* retrieval and entry of information.
- To support *information* use offered by existing artefacts for patient care,
- To provide preferred *communication modes* to support work practices.

These design goals then helped inform new technology designs which encompass existing and augmented information artefacts and take advantage of the distributed information sharing affordances of digital technologies. This in turn led to the following contribution.

9.2.6 Prototyping and Evaluating Technology Design

This dissertation demonstrated that Paper and Digital Integrated Charting can be prototyped using a combination of varying-fidelity methods to demonstrate the design concepts and to actively draw the participants into the design dialog. The Paper and Digital Integrated Charting aims to bridge the gap between the way nurses use pen and paper to record notes and observations taken at the point of care and how they feed this information into the electronic record (Chapter 8). The knowledge acquired from a focus group study to evaluate this technological prototype led to the refinement of the set of design guidelines for designing technologies to support nurses' personal information space and the digital information system (Section 8.6). These recommendations suggest that technologies should be designed to:

- Support flexibility and personalization
- Facilitate information entry and retrieval
- Provide an overview
- Support 'personal' information use
- Safeguard the accuracy of information
- Support system dispersal

These recommendations were specifically designed to develop technologies that facilitate the use of personal information space and easy conversion to the digital medium. They also provide advice for creating an easy-to-use tool to fit into existing work practices. Thus it is hoped that this research will spark increased interest in the development of new technology focusing on supporting current work practices.

9.2.7 Further Discussion

This research confirms the value of several research practices from the fields of HCI, CSCW and healthcare services research. Several aspects of the approaches used in the studies conducted in this research proved particularly valuable. The use of these practices in this research illustrates how they can be generally applied in studies for evaluating new technologies.

First, establishing a baseline for future studies provides important benchmarks for evaluating new technologies (Chapter 3). Second, it is important to evaluate against established objectives yet also remain receptive to discovering unexpected outcomes of new technology (Chapters 4 and 6). Third, the use of triangulated research methods shows clear benefits to studying the research problems (Chapters 3, 4 and 6). For example, direct observations were used to identify phenomena that participants may not report and interviews were conducted for clarifications and explanations for the participants' actions in the field studies. Fourth, conducting data collection at different time frames helps uncover short- and long-term phenomena (Chapters 4 and 6). This in turn helps direct resources to improving desired issues. Fifth, examining artefacts at different times provides a convenient way to identify how they are actually used (Chapter 3) since it is generally time-consuming and labour-intensive to follow participants in order to find out how they use artefacts. Sixth, an analysis method that combines framework-based communication strategies and fish-bone representation was developed for investigating impact of new technology deployment (Chapter 6). Finally, this dissertation contributes several potential design ideas for additional support for improving nurses' information flow (Section 7.2).

9.3 Future Work

The results from this dissertation indicate several directions that warrant further study. These directions include further prototyping and evaluation of technology designs for supporting various aspects of nurses' information flow, further exploration of information flow practices in other contexts and settings, and investigating whether the InfoFlow Framework is applicable to other settings including other hospital settings and other high-reliability domains.

9.3.1 Further Prototyping and Evaluation of Technology Design

9.3.1.1 Iterating Paper and Digital Integrated Charting

In Chapter 8 I introduced and prototyped a Paper and Digital Integrated Charting approach for bridging the use of paper personal notes and the conversion from handwriting to digital text. The focus group study presented in that chapter was an initial step in iterating the design of this charting approach described in Section 7.2. While the feedback gathered from the study indicated that this integrated charting approach was useful for supporting current practices in information flow and to facilitate the charting process, the study also proposed several possible improvements in Section 8.5.2. The provision of 'personal' information space should be sufficiently easy to use that nurses can conveniently write information down in appropriate regions on their personal notes so that nurses can still freely make use of 'personal' information necessary for their work. It was also suggested to link the charting interface with the embedded structures (e.g., flow sheets) of the electronic health records through a button or by replacing the digital information structure with more intuitive interaction using digital pen and paper technology. This enhancement would enable more efficient documentation of the medical information that emerged during a shift, thus allowing more time for actual patient care.

Although the quality of handwriting recognition did not appear to be a big issue in the study, it warrants further investigation as the success (e.g., the time savings in charting) of this approach may be affected by the quality of the handwriting conversion. It is expected that commercially available advanced software applications for handwriting recognition would deliver more desirable conversion quality but since handwriting recognition is still an active research area in itself, this may be an issue that will require further investigation. Besides, since symbols and abbreviations are frequently used in the personal notes, the investigation should also identify a handwriting recognition application that can intelligently differentiate a customized set of symbols and abbreviations while other symbols and abbreviations can be easily and dynamically added to the list so that clinicians can continue to use these familiar terms and symbols for their work.

9.3.1.2 Prototyping and evaluating other technology design

In addition to the Paper and Digital Integrated Charting approach, Chapter 7 also proposed several other technology designs (Section 7.2). These designs were intended to improve specific aspects of the information flow, for instance, to provide distributed access to information inscribed in patient charts, to offer remote entry and retrieval of shift reports while providing an overview of the operation, and to allow note-taking and information retrieval through voice command. Thus, a next step of this research is to prototype and to evaluate these designs to find out if and how the technology designs can improve the information flow. An iterative approach for prototyping of these technology designs is recommended.

9.3.2 Further Explorations of Information Flow Practices

The specific setting where the studies presented in this dissertation were conducted exhibited complex information flow practices during shift change in which nurses are required to assemble information from a variety of distributed information media while outgoing nurses disassemble information. An understanding of information flow practices in other contexts (e.g., multidisciplinary information flow) or settings (e.g., another ward or another hospital) would be valuable to compare and contrast their similarities and differences. This knowledge can also help validate and generalize the InfoFlow Framework developed in Chapter 5 for applying to other contexts and settings.

9.3.3 Applying the Framework to Other Settings

Despite the fact that the InfoFlow Framework has been successfully used to assess the impact of a new communication technology and to generate new technology design for supporting information flow in our study ward, these results found in the specific setting of this study ward may not generalize to other settings.

Two possible research directions are: First, exploring the use of the framework to evaluate new technologies and/or to generate new technology designs for supporting information flow in other hospital settings could prove rewarding. For example, information flow is also important across multidisciplinary teams and this may share factors with the nurse-focused InfoFlow Framework. Second, investigating to what extent the framework could be applied to non-hospital settings including other high-reliability domains such as air traffic control, would also be interesting. This type of research would allow us to start to examine to what extent the framework is generalizable.

9.4 Conclusion

This dissertation has shown that designing technologies to support nurses' information flow greatly benefits from in-situ investigation of work practices pertinent to information flow. This research has provided a careful and in-depth investigation of basic information flow practices, which has led to a better understanding of the nuances of the nurses' activities, media and their interactions, as well as the development of a framework that can be used for evaluating technologies and generating technology designs. This research has also provided a longitudinal study on the use of a newly deployed mobile technology, which has led to the understanding of the importance of "old-fashioned" paper artefacts in supporting nurses' information flow. This discovery has led us to a new design which is directed towards bridging the intuitive paper artefact and the distribution-enabled digital medium. This research has provided many contributions to the process of designing technologies to support information flow, yet as discussed above, there is still a great deal to be done before digital technology can seamlessly integrate into existing information flow practices.

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Appendix A. Observational Study

A.1 Nurse Consent Form

Title: Observational study on the information flow during shift change in the Ward of the 21st Century in the Foothills Hospital

Sponsors: Alberta Ingenuity Fund, iCore, Natural Science and Engineering Research Council

Investigators: Dr. Sheelagh Carpendale, Charlotte Tang, Dr. Saul Greenberg, Dr. Ron Wardell and Dr. Barry Baylis

This consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail, please ask.

Background

The objective of this study is to understand and identify how information is communicated between nurses during the brief handshake of shift change. We will collect primarily qualitative data and some quantitative data during the observations. This knowledge will then be translated into design considerations for a computer-based system for supporting the information flow.

Minimally-intrusive observations, interviews and questionnaires will be conducted over a period of approximately eight months. Observations and interview notes will be recorded by pen and paper. We may also audio-tape, video-tape or photograph for later analysis. In all circumstances, only the investigators (as stated above) involved in this study have access to raw data collected (e.g., observation notes and videos, interview transcripts) and identities of participants will be kept anonymous in any publications or reports of the study.

Our method will involve observing nurses inside the shift change room, in and around the computer stations, and the main nursing station during shift change. We will also observe how reporting to the patient-care manager/charge nurse is conducted. Our study aims to see how information is communicated and how artifacts (e.g., whiteboards and computer printouts) are used for the communication. Short informal interviews may be conducted when necessary for clarification purposes. Questionnaires will also be used to collect participants' experiences of the current system and their opinion for improvements.

What Would I Have To Do?

We ask you to carry out your daily routine as you normally do since unobtrusive observations will be conducted during shift change. You may be asked for short interview(s) to clarify our observations when necessary and when situation permits. We will also send you a questionnaire asking for your personal experiences regarding shift change and any other comments you may have.

What Are The Risks?

Participation in this study will not put you at any known risk or harm and is strictly voluntary. Only the researchers involved will have access to the collected data. All information regarding your personal information and those that could identify you is confidential.

Will I Benefit If I Take Part?

The purpose of this study is to inform the design of technology to support the information flow during shift change. Therefore your participation will help us identify issues for the design, which will benefit your work in the long run.

Do I Have To Participate?

Participation in this study is entirely voluntary. Should you prefer not to participate, we will not disclose this information to anyone other than the investigators of this study.

Will My Records Be Kept Private?

Only the investigators of this study will have access to the raw information collected. Anonymity will be preserved in publications so that individual participants cannot be identified.

If I Suffer A Research-Related Injury, Will I Be Compensated?

In the event that you suffer injury as a result of participating in this research, no compensation will be provided to you by the Alberta Ingenuity Fund, iCore, the Natural Sciences and Engineering Research Council, the University of Calgary, the Calgary Health Region or the Researchers. You still have all your legal rights. Nothing said in this consent form alters your right to seek damages.

Signatures

Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the investigators, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

If you have further questions concerning matters related to this research, please contact: Charlotte Tang, Dr. Sheelagh Carpendale, Dr. Saul Greenberg, Dr. Ron Wardell or Dr. Barry Baylis of University of Calgary, tangsh/sheelagh/saul@cpsc.ucalgary.ca, rwardell@telusplanet.net or baylis@ucalgary.ca.

If you have any questions or issues concerning your rights as a possible participant in this research, please contact the Associate Director, Internal Awards, Research Services, University of Calgary, at 220-3782.

Participants Name Signature and Date

Investigator/ Delegate’s Name Signature and Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

A signed copy of this consent form has been given to you to keep for your records and reference.

A.2 Patient or Surrogate Consent Form

Title: Information Flow: Observational Study of the Ward of the 21st Century in the Foothills Hospital

Principal Investigator: Dr. S. Carpendale

Grant ID: 18936

Sponsors: Alberta Ingenuity Fund, iCore, Natural Science and Engineering Research Council

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

What is going on?

The Ward for the 21st Century (W21C) aims to improve healthcare in every way. This particular study is part of the bigger plan. In every hospital, nurses going off shift tell nurses going on shift about patients under their care. This is important to ensure that you the patient receive continuity of care. We are trying to find out how this is done, and whether new technology can improve the communication between nurses. If we improve the communication between nurses it is likely that this will improve the care to all patients.

You do not have to do anything but we are asking for your permission

In our study we focus on what the nurses do as they tell one another about patients at shift change. We watch the nurses, listen to them, and do a video and audio tape. While we are only interested in how the nurses pass information, we will hear some details about you and your condition. Since this is personal health information we need your permission before the nurse can give information about you at shift change during the study.

Is my information confidential?

The information that we will hear will be very brief, your name may not even be used, and all of the investigators have signed an agreement to keep information confidential.

What will happen if I do not give permission?

You will still receive standard care. However when we videotape the shift change information about you will not be included. We will mark your chart clearly to ensure that your health information is not included in this study.

If you want to know more call: Charlotte Tang at 210-9499 or 880-8890

"If you have questions concerning your rights as a possible participant in this research, please contact the Associate Director, Internal Awards, Research Services, University of Calgary at 220-3782"

______________________________   ______________________________

Participant's Name   Signature and Date

______________________________   ______________________________

Surrogate's Name   (if applicable)   Signature and Date

______________________________   ______________________________

Witness' Name   Signature and Date

This study has been approved by the Conjoint Health Research Ethics Board. This consent form will be filed in your chart.

A.3 Photograph Consent Form

Research Project Title: Observational study on the information flow during shift changes in the Ward of the 21st Century in the Foothills Hospital

Investigators: Dr. Sheelagh Carpendale, Charlotte Tang, Dr. Saul Greenberg, Dr. Ron Wardell and Dr. Barry Baylis

This consent form authorizes the investigators to use the photographs taken during the study without modification (except for masking identities for anonymity purposes when necessary) for illustrative purposes in the dissemination of the study's results, including but not limited to, presentations and publication of papers and/or theses.

Participants Name and Signature Date

Investigator/ Witness's Signature Date

A.4 Photograph/Video/Audio Consent Form

Research Project Title: Observational study on the information flow during shift changes in the Ward of the 21st Century in the Foothills Hospital

Investigators: Dr. Sheelagh Carpendale, Charlotte Tang, Dr. Saul Greenberg, Dr. Ron Wardell and Dr. Barry Baylis

This consent form authorizes the investigators to use the photographs taken, video and audio recorded during the study without modification (except for masking identities for anonymity purposes when necessary) for illustrative purposes in the dissemination of the study's results, including but not limited to, presentations and publication of papers and/or theses.

Participants Name and Signature Date

Investigator/ Witness's Signature Date

A.5 Ethics Approval

FACULTY OF MEDICINE | UNIVERSITY OF CALGARY

OFFICE OF MEDICAL BIOETHICS
Room 93, Heritage Medical Research Bldg
3330 Hospital Drive NW
Calgary, AB, Canada T2N 4N1
Telephone: (403) 220-7990
Fax: (403) 283-8524
Email: omb@ucalgary.ca

2006-05-30

Dr. Sheelagh Carpendale
MS 680, Faculty of Computer Sciences
University of Calgary
Calgary, Alberta

Dear Dr. Carpendale:

RE: Information Flow: Observational Study of the Ward of the 21st Century in the Foothills Hospital

Ethics ID: E-18936

PhD Students: Ms. C. Tang; Mr. M. Hancock

The above-noted proposal including the Research Proposal , Questionnaire (Version :1.0 dated: December 07, 2005), Information Letter (Questionnaire Information Sheet (Version 1.0 dated December 7, 2005)), Consent Form (Surrogate Consent Form, Consent Form (Version 1.0 dated May 30, 2006)), Poster has been submitted for Board review and found to be ethically acceptable.

Please note that this approval is subject to the following conditions:
(1) appropriate procedures for consent for access to identified health information have been approved;
(2) a copy of the informed consent form must have been given to each research subject, if required for this study;
(3) a Progress Report must be submitted by May 30, 2007, containing the following information:

- i) the number of subjects recruited;
- ii) a description of any protocol modification;
- iii) any unusual and/or severe complications, adverse events or unanticipated problems involving risks to subjects or others, withdrawal of subjects from the research, or complaints about the research;
- iv) a summary of any recent literature, finding, or other relevant information, especially information about risks associated with the research;
- v) a copy of the current informed consent form;
- vi) the expected date of termination of this project.

4) a Final Report must be submitted at the termination of the project.

Please note that you have been named as the principal collaborator on this study because students are not permitted to serve as principal investigators. Please accept the Board's best wishes for success in your research.
Yours sincerely,

Ian Mitchell, MA, MB, FRCPC
Acting Chair, Conjoint Health Research Ethics Board

IM/gk
c.c. Adult Research Committee
Ms. C. Tang & Mr. M. Hancock (Students)
Dr. Ken Barker (information)
Office of Information & Privacy Commissioner
Research Services

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Appendix B. Baseline Observational Study

B.1 Example codes for baseline observational data

Meaning	Codes I	Codes II
ask colleague for help	AHELP	INFO ASSEMBLY
at nursing station	NS	DISTRIBUTED
charge gives instructions	INSTRUCT	INFO ASSEMBLY
charge reporting	CREPORT	INFO DISASSEMBLY
charge-to-charge reporting	C2CREPORT	CHARGE ACTIVITY
check on patients	PATIENT	INFO ASSEMBLY
checkbox	CHECKBOX	VISUAL ATTRIBUTE
circle PCS	CPCS	VISUAL ATTRIBUTE
clarify with other clinicians	CLARIFYO	INFO ASSEMBLY
clarify with other nurses	CLARIFYN	INFO ASSEMBLY
offer help	OHELP	INFO DISASSEMBLY
color code	CC	VISUAL ATTRIBUTE
computer charting	CCHART	INFO DISASSEMBLY
computer trouble	COMPTROUBLE	DIFFICULTY
cut notches on PCS	NOTCH	VISUAL ATTRIBUTE
discuss patient assignment	JTALK	INFO ASSEMBLY
folded worksheet in pocket	WSPOCKET	PREFERENCE
get Med list	GMEDLIST	INFO ASSEMBLY
give verbal report	VREPORT	INFO DISASSEMBLY
highlight PCS	HPCS	VISUAL ATTRIBUTE
highlight worksheet	HLWS	VISUAL ATTRIBUTE
in ward wing	WING	DISTRIBUTED
interruption	INTERRUPT	DIFFICULTY
large writing for reminders	LARGEFONT	VISUAL ATTRIBUTE
look for incoming colleague	FINDIC	DISTRIBUTED
look for outcoming colleague	FINDOG	DISTRIBUTED
mentor new nurse	MENTOR	TRAINING
missing patient chart	MISSPC	DIFFICULTY
missing report on whiteboard	MISSRWB	DIFFICULTY

need a task timeline	TIMELINE	WISH LIST
negotiate patient assignment	NEGOTIATE	INFO ASSEMBLY/DISASSEMBLY
no missing report on WB	FULL REPORT WB	INFO DISASSEMBLY
offer personal opinions towards patients	OPINION	INFO DISASSEMBLY
outgoing offer verbal report	OVERBAL	INFO DISASSEMBLY
patient info on notches	INDEX	VISUAL ATTRIBUTE
post report on whiteboard	PRW	INFO DISASSEMBLY
post-it for extra notes	POSTIT	VISUAL ATTRIBUTE
questions and answers at verbal	Q&A	INFO ASSEMBLY/DISASSEMBLY
read from charge board	RCHARGE	INFO DISASSEMBLY
read nurse assignment	RNA	INFO DISASSEMBLY
read patient chart	RCHART	INFO DISASSEMBLY
read PCS	RPCS	INFO DISASSEMBLY
read report on whiteboard	RWB	INFO DISASSEMBLY
refer to notes	RNOTES	INFO DISASSEMBLY
remove outdated info	CROSSOUT	VISUAL ATTRIBUTE
bed management	BED	INFO ASSEMBLY/DISASSEMBLY
report patient's social info	RSOCIAL	INFO DISASSEMBLY
sit around table	RTABLE	SOCIAL
social interaction	SOCIAL	SOCIAL
take notes from whiteboard report	WRP	INFO DISASSEMBLY
textlines	TEXTLINE	VISUAL ATTRIBUTE
update other clinicians instructions	UPDATECOMP	INFO DISASSEMBLY
use a clipboard	CLIPBOARD	PREFERENCE
use different color duirng shift	NEWCOLOR	VISUAL ATTRIBUTE
use gesture	GESTURE	INFO DISASSEMBLY
use PCS only	PCSonly	PREFERENCE
use standard worksheet	SWS	PREFERENCE
use symbols or notations	SYMBOL	VISUAL ATTRIBUTE
use wite-out for correction	CORRECTION	VISUAL ATTRIBUTE
use worksheet	WS	PREFERENCE
verify report on WB after composing	VERIFY REPORT	INFO DISASSEMBLY
wait in line	WAIT	DIFFICULTY
write notes in specific locations	SPATIAL	VISUAL ATTRIBUTE
write on charge board	WCHARGE	INFO DISASSEMBLY
write on patient chart	WCHART	INFO DISASSEMBLY
write on PCS	WPCS	INFO DISASSEMBLY

medical information	MEDINFO	INFO
verbal info	VERBAL	MEDIA
display info	DISPLAY	MEDIA
info on paper	PAPER	MEDIA
digital info	DIGITAL	MEDIA
offload information	OFFLOAD	INFO DISASSEMBLY
read computer report	RDIGITAL	INFO DISASSEMBLY
info overload	OVERLOAD	DIFFICULTY
prefer paper	PREFER PAPER	PREFERENCE

B.2 Personal Notes Analysis

As described in the baseline observational study in Chapter 3, copies of nurses' personal artefacts - paper personal notes and patient care summaries - were collected both at the beginning and at the end of their shift. The contents placed in the personal notes and the highlighted texts and annotations inscribed in the patient care summaries were examined, extracted, and tabulated. The following is an abstraction of the tabulation for 25 distinctive personal paper artefacts collected during the study.

Different kinds of personal notes were first listed as columns (shown in second row): standard worksheet (5), plain paper (10), self-prepared printed template (5), and patient care summary (5), where the number in the brackets refers to the number of that particular type of personal notes collected. By examining the personal notes, a list of information content types are extracted and listed as shown in the first column, e.g., tests, vital signs, scheduled medications, and PRNs. Attributes such as highlighting, use of text lines and checkboxes, and sketches that were used in association with each kind of information content types were tabulated. Finally, a new set of information function types, e.g., to-do, prompts, and demographics, was used to code the functions as used with the information content types.

Information function types

	Types of Personal notes				
Types of Information	Standard worksheet (5)	Plain Paper (10)	Self-prepared Printed Template (5)	Patient Care Summary (5)	"Information Function" & Design Implications
Format	2 rows/patient (3) 1 row/patient (2)	patient/row (7) patient/column (1) quadrants (2)	patient/row (4) patient/column (1)	notched + highlight (4) notched only (1)	allow different format (per row, per column, quadrants, with tabs)
Name	full name (3) last + initial (2)	full name (9) -highlighted (1) -in bounding box (1) last name only (1)	full name (5) - in red & highlighted (1) (all under specific label or column)	write on cutline + highlight (3) name only on cutline (2)	"***demographics***" Full name or last + initial
Room/Bed No.	in "room" column (2 digit) (5)	not indicated (2) in specific location (8) - 4 digit (2) 3-digit (1) in bounding box (1)	with room no. (5) - in red (1) 4-digit (1) (all in specific labels or location)	write on cutline + highlighted (3) - also highlight in text (1) room no. in text only (3)	"***demographics***" choice of 2 or 4-digit room number
Age	in "name and Dx" column (5)	with age (9) - in circle (1) angle-bracket from name (1)	not indicated (2) in specific place (3) - in red (1)	write on cutline + hightlighted, highlight in text (1), age in text only (3)	"***demographics***"

Gender	not shown (5)	M/F (1) icons (1)	not shown (3), in red (1), all in specific place	icons on cutline + highlighted gender in text	"***demographics***" M/F or icons
Allergies	not shown (5)	in specific place (2) -1 in perpendicular orientation, -write "allergy" (1), not shown or N/A (7)	in specific place (2), not indicated (3)	highlighted in text (1), allergies as printed (4)	"***alerts***" highlights icons e.g., heart
Admitting Dx	all under "name & Dx" column	in specific place (10) -label Admit Dx (1) -in B/B (1)	in specific place (5) -1 in red	highlighted (5)	"***alerts***" "***demographics***"
History	under "Name & Dx" column (2), not shown (3)	in specific place (3), not shown (7)	not indicated (2), in specific place (3)	highlighted (2), circled (1), N/A (1)	"***historical***"
Diet	All in "Diet" column, -circle or write down special diet	in specific place (7) with one with B/B, not shown (3)	in specific place (4), not shown (1)	highlighted (1), note on left margin (1), as printed (3)	"***alert***" a list of diets to choose
Current Issue/ treatment plan	in "Procedures & treatments" column (3), in "misc" column (2)	in specific place and in specific format (9) - textlines, checkboxes, as list of numbered priorities, highlighted cell	in specific place (4), not shown (1)	highlighted (3), write on front page (2) - on right side (1)	"***to-dos***", "***scheduling***", "***prompts***" -numbered list "***reporting***" -assessment of response
Dr name	in "Name & Dx" column (2), in "room no." column (1), not shown (2)	not shown (4), in special place (6) -diff orientation (1) -in brackets (1)	in specific places (5) - in red and highlighted (1)	Highlight Dr. name on front page (1), as printed (4) - highlighted Dr. name to contact in special situations in other pages (1)	"***demographics***" , "Medical Team"
Code Level	in "Rm no." col. (3) - L-2 (1), in "Name" col. for not level 1 (1), not shown - maybe all L1 (1)	All in specific place --inside a heart shape (3), -circled (2), -not shown L1 (2)	in specific place (4) -circled (2) -circled with roman numeral (1) -highlight (1), -not shown (1)	highlight text only (1), -write on cutline + highlighted (3), -write at centre bottom + highlight (1)	"***alert***" highlight, icons e.g., circle, heart
Scheduled Medication	not shown (1), -in "Meds" col with checkboxes (1), -"meds" col for assessments (2) -for PRNs (1)	show time + textline (4) -checkbozes (1) -time highlighted(1) -not shown (6)	not shown (4), times shown as a list for circling (1)	as printed (3), text highlighted (1), times listed at bottom of front page e.g., 16 20 22	"***to-do***" -show time intervals, highlight, "***prompts***" -with textline and checkboxes, "***reporting***" -for refusal and reason and response to meds
PRN	in "Meds" column (3) -drugs, time and checkboxes (1), -not shown (2)	not shown (1), in specific places (9) - drug, dose, time	all in specific places -drug name (5), -dose (2), -time (5), -checkboxes (2)	write on front page (2) - dose, name, time; as printed on text (2); highlighted (1)	"***prompts***" "***reporting***" -drug name + textline, does, times, checkboxes for status, and highlight

IV	in "IV" column (4); not shown (1)	not shown (3); in specific places (7) -in priority list (1), -tick in checkbox for done (1), -textline (1)	in specific places (4) -textlines (3); not shown (1)	highlight text (1); write on front page (1); as printed on text (1); not shown (2)	"***to-do***" "***reporting***" "***prompts***" textlines + checkboxes and highlights
Blood Work	in "Specimens" column (4) -textline for measurement (2), checkbox for status and text for measurement (1); in both "Specimen" and "Procedures" columns as one column (1)	all in specific places (2) - inside B/B, previous shift data in brackets (1), big checkmark for "OK" (2) with textlines (2)	all in specific places -label "Lab" (2), -in "Misc" column (1), -with textline (1)	All in specific places - circled alert condition and time (1)	"***to-do***" "***reporting***" -B/B, "***prompts***" - textlines and checkboxes, "***alert***" -to alert condition to notify doctor immediately, "***historical***" -place in ( ) to show previous values
I/O	All in "I/O" column, different presentations, textlines, or like a table	not shown (7); as priority list with current issues (1); inside B/B (1), I/O with condition to notify doctor (1)	in specific places with labels (4) -checkbox, textline and like a ledger; not shown (1)	write on front page (4) – textline (1); not shown (1)	"***to-do***" -as a list; "***prompt***" -textlines and checkboxes; "***reporting***"
Vital Signs	in "V/S" column in column form (1) written in green color	all in specific place and speciic format (8) -in column form -enclosed in bounding boxes (3); -1 rpw for v/s (2) -multiple rows for multiple sets	in column format (4) -textlines and multiple columns; in row format (1)	all in specific places; V/S always comes in sets; in column format with textline (2); in row format with text lines (2)	"***prompts***" -textlines and bounding boxes; "***reporting***"
Labs	all in "Specimens" column; -textlines (2) -textline & checkboxes (1)	in specific places (8) - texline + time highlighted (1) -old number in bracket (1); not shown (2)	in specific places (4) -textline for ticks (1); not shown (1)	write on front page (4), not shown (1)	"***prompts***" -textlines and checkboxes, highlights and time; "***reporting***", "***historical***" -old values in brackets
Tests	all in specific areas; in "Procedures" (3) -textline and checkboxes (1); in "specimens" (1); in "Misc" -checkboxes (1)	in specific area (8) -textlines and checkboxes (1); not shown (2)	all in specific location; -textlines for ticks (1) –checkboxes (1)	write on front page (4); not shown (1)	"***prompts***" -textlines and checkboxes; "***reporting***"

Assessment	in specific place -textline and checkboxes (1); -pictures for lungs + ticks for ok (1) not shown (1)	in specific place (7) -in point form (1); -uses the 6 standard V/S assessment and sepcific ones for each patient (1); not shown (3)	not shown (3); in specific place (2)	in specific locations (3) -use symbols by shading or ticking for assessments (1) not shown (2)	"***to-do***" "***reporting***"; "***prompts***" -textlines + checkboxes; symbols or pictures to show condition and vital signs as part of assessment
Issues	in specific coln (4) –with times and textline (1); not shown (1)	in specific place (5) -rewrite issues of special attention (1); not shown (5);	all in specific place; textlines for ticks (1)	not shown (1); highlight text (1); in specific place (2); several places on front page	"***prompts***" -textlines, times and highlight; "***reporting***"
To-dos	textlines only (2) -ticks for done (1); textlines + checkboxes (2); not shown (1)	use textlines (9) -highlights (1), checkmarks (1), question mark (1), checkboxes (2), checkboxes + highlight 91); not shown (1)	not shown (2); -use textlines (3) - heckboxes (1), labels are highlighted including number of v/s to take at beginning of shift (1)	all use textlines for assessments; use checkboxes for status (4); texts are highlighted -front + other pages(2) circle text (1)	"***prompts***" -textlines, checkboxes, highlight (label), "***verification***" -question mark for finding out more info, and circle
Held orders				cross out in pen (1); write on front page (1)	
Report from Previous Shift	not shown (4); in "Misc" column (1)	memorize (2); write on patient care summary (1); in specific place (4) -in bracket for reference (1), -write last two shifts' report (1)	in specific place (4) -in green pen; not shown (1)	write on front (specific place) (3); not shown (2)	"***historical***" -mostly last info and put in brackets for comparison
Actions during shift	use several different colors for different things (1)	use different-color pen, tick + circle things and write on textlines (2); cross out things after charting (1); big ticks for charted items (1); use symbols like different arrows to refer to current/ historical info	use different-color pen (2); write "Charted" in green after charting	use different-color pen; fill in measurements in textlines; tick checkboxes; write notes on front page	different color input; ticks, circles, cross out; icons to show charted; symbols for additional meaning e.g., brackets + angled arrows for historical and straight arrow for current issues; write notes and annotate
Comments					other categories: independence level, isolation alerts, group assignment letter, MPR - for scheduling; other forms: MPR charting for reporting

Appendix C. Computer-On-Wheels Study

C.1 Example codes for the early stage study

COW - early stage	Code I	Code II
adjust personal notes	ADJUSTED NOTES	CONTINUAL PAPER USE
ask college for help	AHELP	INFO ASSEMBLY
have problem recalling notes on personal notes	BAD MEMORY	PAPER USE
charge-to-charge reporting	C2CREPORT	INFO DISASSEMBLY
color-coded medlist	CC MEDLIST	IMPACT OF NEW EHR
different highlight color for different content on worksheet	CCWS	PAPER USE
charge nurse asked a nurse to take charge reporting on her/his behalf	CHARGE SURROGATE	INFO ASSEMBLY
look for info for clarification	CLARIFY	INFO ASSEMBLY
ask colleague to co-sign on drug dispense	COSIGN	PATIENT CARE
bring COW to patient room in initial round	COW INITIAL ROUND	PATIENT CARE
will only use a COW when no others are available	COW LAST CHOICE	CHOICE OF COMPUTER
don't know what term to use for searching	TERMINOLOGY USE	
always bring COW to patient room and enter assessments directly to EHR	COW TO ROOM	IMPACT OF COW
remove outdated info	CROSSOUT	PAPER USE
found computer room too crowd	CROWDED CR	SETTING ISSUE
work station too crowded	CROWDED WSTATION	ERGONOMIC ISSUE

doctor gives instruction to nurses	DOC INSTRUCT	INFO ASSEMBLY
EHR as primary info source	EHR PRIMARY	INFO ASSEMBLY
outgoing looks for incoming	FINDIC	INFO DISASSEMBLY
incoming looks for outgoing for verbal report	FINDOG	INFO ASSEMBLY
enter free-form text	FREE FORM TEXT	SOFTWARE ISSUE
need to switch hands between pen and mouse	HAND SWITCH	ERGONOMIC ISSUE
only report high-level info	HL INFO	INFO DISASSEMBLY
highlight worksheet	HLWS	PAPER USE
prepare shift at a COW in hallway	HW COW	CHOICE OF COMPUTER
use a desktop at end of a hallway	HW END DESKTOP	CHOICE OF COMPUTER
competing with COW for space in hallway	HW SPACE CRUNCH	ERGONOMIC ISSUE
getting instruction from charge nurse	INSTRUCT	INFO ASSEMBLY
use personal notes made on the first day of assignment to add new information to save some time	KEEP WS	TIME ISSUE
COW always has to be plugged in	SHORT BATTERY LIFE	TECHNICAL ISSUE
less reports on whiteboard	LESS WB	TIME ISSUE
feel lonely	LONELY	LESS SOCIAL INTERACTION
mentally convert feet to metres	MANUAL UNIT CONVERSION	COMPROMISE PATIENT SAFETY
medical information	MEDINFO	INFO ASSEMBLY
missing patient chart	MISSPC	INFO ASSEMBLY
more spatial movements	MORE MOVEMENT	LESS TIME FOR PATIENT CARE
more verbal reports	MORE RVERBAL	TIME ISSUE
need more time	MORE TIME	LESS TIME FOR PATIENT CARE

takes more time prepare meds with the computer system	MORE TIME MEDS	LESS TIME FOR PATIENT CARE
flip through screens is time-consuming	NAVIGATION TIME-CONSUMING	TIME CONSUMING PREPARATION
work on new admission paper work	NEW ADMIT PAPER	IMPACT OF COW
does not like to bring COW to patient rooms	NO COW TO ROOM	COW PROBLEM
left-handed nurses do not need to switch hands between pen and mouse	NO HAND SWITCH	ERGONOMIC ISSUE
Rush to prepare meds before power-off	RUSH MED PREP	PATIENT SAFETY
notebook computer	NOTEBOOK	CHOICE OF COMPUTER
charge nurse too busy so OG wrote on the charge board	OG WCHARGEBOARD	TIME ISSUE
unit clerk listen to verbal report and offer information	OHELP UC	PERSONAL OPINION
offer opinion about patients and share experience	OPINION	PERSONAL OPINION
make positive opinions towards patients	OPINION+	PERSONAL OPINION
have specific order of accessing different information sources	ORDER	ROUTINE
looks up paper reference books	PAPER REF	PAPER USE
responding to patient family's questions	PATIENT Q&A	INTERRUPTION
carry pen and highlighter of diff colors	PEN+	PAPER USE
screen turned off during med preparation	POWER SAVE PROBLEM	COMPROMISE PATIENT SAFETY
prefer paper med list	PREFER PAPER MEDLIST	PAPER USE
read patient chart	RCHART	INFO ASSEMBLY
read entire record	READ ALL EHR	TIME CONSUMING PREPARATION
have to always plug in	PLUG IN	MOBILITY ISSUE

sit at a COW to read EHR	REHR COW	USE COW
personal notes as reminders	REMINDER	PAPER USE
reads lab test results with red arrows only	RFLAGS ONLY	ALERT OF NEW INFO
refer to personal notes	RNOTES	PAPER USE
scroll down long lists to find info	SCROLL	TIME CONSUMING PREPARATION
social interaction at NS	SOCIAL NS	LESS SOCIAL INTERACTION
special nurse comes to provide assistance	SPECIAL HELP	PATIENT CARE
use standard worksheet	SWS	PAPER USE
use symbols and notations	SYMBOL	PAPER USE
type with left hand	TYPE OTHER HAND	ERGONOMIC ISSUE
use worksheet paper	WS	PAPER USE
use worksheet inside patient rooms	WS IN RM	PAPER USE

C.2 Example codes for the late stage

COW - late stage	Codes	Themes
difficult to adjust the height of COW	ADJUST HT	NEW PROBLEM
move mouse to restart hibernating computer	ADJUST MOUSE	IMPROVEMENT
COWs have battery problems	BATTERY PROBLEM	WORSE PROBLEM
sticky wheels	ERGONOMIC ISSUE	NEW PROBLEM
connectivity problem	CONNECT PROBLEM	WORSE PROBLEM
dead zones	DEAD ZONES	WORSE PROBLEM
demographics already printed	DEMOGRAPHICS	IMPROVEMENT
dislike reading EHR in hallway	DISLIKE REHR HW	PERSISTENT PROBLEM
doctors continue to write consults on patient chart	DOC WCHART	PAPER USE
found EHR info confusing	EHR CONFUSE	SOFTWARE PROBLEM
look for a COW to use	FIND COW	WORSE PROBLEM
look for a stool to sit	FIND STOOL	PERSISTENT PROBLEM
always plug in	PLUG IN	WORSE PROBLEM
COWs parked in hallways	IMMOBILE COW	WORSE PROBLEM
look for a working computer	FIND WK COMPUTER	WORSE PROBLEM
tried several COWs before one works	FIND WK COW	WORSE PROBLEM
use a COW in hallway to read EHR	HW COW	CHOICE BY SET UP
more routers are planned to improve the dead zones	IMPROVE PLAN	IMPROVEMENT
page on intercom	INTERCOM BROADCAST	

discover different interfaces of EHR	INTERFACE	IMPROVEMENT
interrupted by patient	INTERRUPT	WORSE PROBLEM
save time as no need to go to nursing station every hour to get a med list	LESS MOVEMENT	IMPROVEMENT
MDP chart on EHR	MDO CCHART	IMPROVEMENT
MDP write on patient chart	MDP WCHART	PAPER USE
used desktop computer in hallway to prepare medicines	MED HW DESKTOP	MED PREP
medication list per patient per screen	MEDLIST PP	PERSISTENT PROBLEM
mentor a new student nurse to prepare personal notes	MENTOR PAPER	NEW PROBLEM
personal notes very messy	MESSY NOTES	PAPER USE
took more time to read EHR	MORE TIME	PERSISTENT PROBLEM
need to have chairs with good back support	NEED CHAIR SUPPORT	PERSISTENT PROBLEM
read info with flags	NEW INFO FLAG	IMPROVEMENT
existing stools has no back support	NO BACK SUPPORT	PERSISTENT PROBLEM
no view for meds for all patients	NO MEDS OVERVIEW	MED PREP
use paper reference	PAPER REF	PAPER USE
used a printed patient list off the computer as worksheet	PL AS WS	PAPER USE
stool are uncomfortable but still better than standing for long time	PREFER STOOL TO STAND	PERSISTENT PROBLEM
move the mouse to reactivate the COW after hearing beeping sound	WORKAROUND TO POWER SAVE MODE	IMPROVEMENT
faster to read the EHR	READ ALL RECORD	IMPROVEMENT
finds flags for last 2 shifts redundant as need to click each one to cancel it at beginning of shift	REDUNDANT FLAGS	PERSISTENT PROBLEM

prefer comfortable chair when reading EHR	REHR COMFORT CHAIR	PERSISTENT PROBLEM
read EHR in computer room	REHR CR	SET UP ISSUE
need to restart computer when connectivity is bad	RESTART BAD CONNECT	WORSE PROBLEM
sit on high stool at a COW in hallway to prepare for shift	SIT ON STOOL	WORSE PROBLEM
more social interaction by effort	SOCIAL	IMPROVEMENT
symbols and notations	SYMBOLS	PAPER USE
wired connectivity on desktops are better and they do not run on power save mode	WIRED GOOD CONNECT	SET UP ISSUE
notebook computer inside shift change room is wireless	WIRELESS NOTEBOOK	WORSE PROBLEM
prefer writing which helps to remember	WRITING HELPS MEMORY	PAPER USE

C.3 Questionnaire

Use of the Computer-On-Wheels

The purpose of this questionnaire is to find out about the use of the "Computer-On-Wheels" (COWs) and the Sunrise Clinical Manager (SCM), as well as their impact on the information flow during nurses' shift change. Results of this questionnaire will be used and reported in an aggregated form. Please feel free to write down additional comments and details in the open spaces wherever necessary. Thank you very much for your time.

1. What shifts do you work?
   Days/Evenings   Days/Nights   Others: ________________________

2. BEFORE the implementation of the COW, did you prepare a personal worksheet in paper at the beginning of a shift?   Yes / No / NA (if you did not work in this ward before using the COWs)
   Comments:

3. Do you currently prepare a personal worksheet in paper at the beginning of a shift?
   Yes / No

4. At the beginning of a shift, which would be your preferred computer and location for reading the SCM? Please pick the top 5 and rank them, 1 being most and 5 being least preferred.

___ The desktop computer inside the shift change room
___ The notebook computer inside the shift change room
___ A COW in a hallway
___ A desktop computer in a hallway
___ A desktop computer at end of a hallway
___ A desktop computer in the computer terminal

___ A desktop computer inside the nursing station

___ A desktop computer on the counter of the nursing station

___ Others (please specify): ________________________________

Comments:

5. a) How long does it usually take you to prepare for a new shift (i.e. first day of your assignment)?

<15min 15min 30min 45min 60min >60min

b) Does it take you more or less time than before the SCM was implemented?

Less / Same / More

6. a) How long does it usually take you to prepare for subsequent shifts (i.e. 2nd, 3rd … day of your assignment)?

<15min 15min 30min 45min 60min >60min

b) Does it take you more or less time than before the SCM was implemented?

Less / Same / More

**For questions 7 and 8, please refer to specifically the COW (not any other computers).

7. During your shift, how often do you:

	Always	Sometimes (Specify when)	Only occasionally (Specify when)	Almost never
Bring the COW to patient rooms?				
Use the COW to look up information?				
Use the COW to enter information?				
Given a choice, use ANY computer closest to you at work?				

8. a) Do you encounter problems when using the COW (the hardware)? Yes / No

b) What kind of problems do you encounter? Please check and specify as appropriate.

	Never	Once in a while	Sometimes	Often	Always	Comments
Connectivity						
Battery						
Power-save mode						
Mobility						

Seating						
Muscle fatigue						
Others (please specify)						

9. a) Do you encounter problems when retrieving information in the SCM (the software)?
   Yes / No

   b) What problems do you encounter? (Please check and specify as appropriate)

	Never	Once in a while	Sometimes	Often	Always	Comments
Don't know where to look						
Too much information to read						
Layout of information						
Others (please specify)						

10. a) Given a choice, which computer do you usually use to prepare medication?

    Desktop computer / COW

    Why?

11. a) Do you consider social interaction among nurses an important part of your work?

Yes / No

Why?

b) Do you have to make an effort to engage in social conversations? Yes / No

c) If yes, what do you do?

d) Where do these social conversations usually take place?

e) How do you find the current setup (including the COWs and the desktops) in regard to supporting social interaction among nurses?

Difficult / Poor / Adequate / Reasonable / Good

Comments:

f) What would you suggest to change to provide a better environment to support team moral and social interaction among nurses?

12. a) Have you ever mentored a new nurse (e.g., a student nurse)?

Yes / No

b) What did you teach him/her when preparing for a shift? (e.g., to write up notes or use only the computers)

13. a) Do you usually write shift reports on the whiteboard or give a verbal report to your incoming peer nurse?

Written shift report / Verbal shift report / Both

b) Why?

14. At the end of your shift, do you require more or less time for charting than before the COWs were implemented?

    Less / Same / More

15. Would you recommend the COWs to be deployed in all the wards?

    Yes / No

    Why?

C.4 Survey Analysis

As described in the computer-on-wheels study in Chapter 4, a questionnaire was conducted with the nurses working on the study ward to find out their feedback towards the deployment of the computer-on-wheels, and if and how their information flow practices have changed as a result. A total of 29 questionnaires were handed out and received. The following provides more detailed breakdowns of the findings that have not been reported in the chapter.

Question 1-3: To find out the shifts that the participants mostly working in and their work practice in the use of paper personal notes.

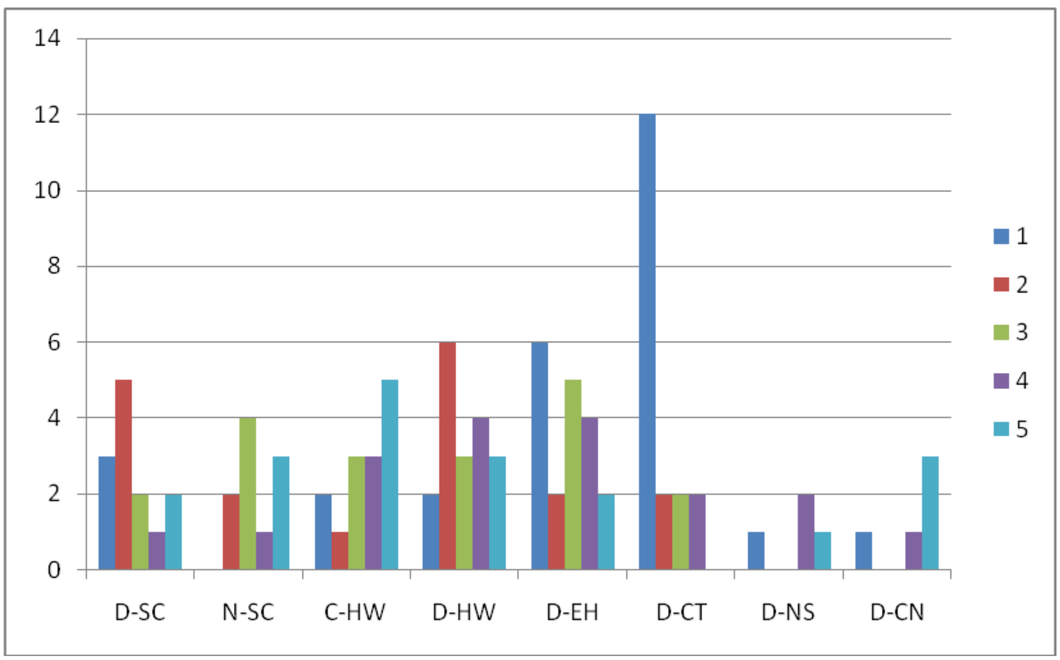
Shifts	Number of Participants
Days and Nights	9
Days and Evenings	17
Days	1
Evenings	1
Casual	1

Personal notes Before COW	Personal Notes After COW	Number of Participants
Yes	Yes	25
No	No	1
N/A	Yes	3

Note: The 3 participants in the last row were new nurses who only started after the deployment of computers-on-wheels.

Question 4: To pick the top 5 preferred computer and location for reading the EHR. Figure C.1 below shows the aggregated findings of the participants' preference towards the use of computers for reading the EHR when preparing for their shift. The legend on the right indicated their preferences, 1 being the most preferred whereas the different kinds of computers are described as follows: D-desktop, N-notbook, C-computer-on-wheels, SC-shift change room, HW-hallway (i.e. ward wing), EH-end of hallway, CR-computer room, NS-nursing station, and CN-counter around nursing station.

In general, participants preferred desktop computers to computer-on-wheels. 25 participants picked a desktop computer, in which 12 picked the desktops in the computer room as their most preferred. Two participants picked computer-on-wheels as their first choice of computers. But one of them only worked in evening shifts, i.e. this participant prepared for his/her shift during day/evening shift when the desktops in the computer room were not available and nurses (both outgoing nurses charting on computers and incoming nurses reading EHR) usually had to compete for the remaining desktops on the ward.



Nurses' preferences for different types of computers (x-axis: types of computers, y-axis: number of participants) (Legend on the right indicates preferences with 1 being most preferred)

Question 5 and 6: Time perceived for preparing for a shift with new assignment of patients and a shift with repeated assignment respectively comparing to before the COW deployment.

11 out of 29 participants perceived that they used the same amount of time for the first and the subsequent shifts while 17/29 participants perceiced that they used less time when preparing for subsequent shifts than when preparing for a new assignment. On average, the participants perceived to require 30.6 minutes (SD = 10.2) and 20.9 minutes (SD = 8.3) in preparing for a new assignment and subsequent shifts respectively.

Question 7: To find out how often the COWs are used during the shift.
The following table shows how often the participants brought a COW into patient rooms when they work and how often they used a COW to enter information and to look up information. The first number represents the total number of responses for the particular frequency whereas the number in brackets refers to the number of qualitative elaborations received. “When desktops are not available” were frequently found in the responses.

	ALMOST ALWAYS	SOMETIMES	OCCASSIONALLY	ALMOST NEVER
Bring a COW To patient rooms	1 - not for isolation rooms	11 - for initial rounds (5), taking vital signs (3), during critical events for unstable patients (3), administering meds or PRNs (3)	12 - taking vital signs (4), providing care to unstable patients (4), during first round (1), in first shift (1), performing specific procedures (1) and when a working COW is available (1)	5 - because COW is too clumsy
To enter information at a COW	14 - still first write on personal notes first, on days only, not ony nights, and when no other computers are available	8 - when desktops with chairs not available (2), for first round (1), new care plan (1), need discharge info (1)	3 - for first round (1), give meds (1), when desktops not available	4 - desktops are unavailable
To look up information at a COW	17 - on days, sometimes at nights (1), when desktops not available	7 - when in hallway (1), new meds info (1), check med schedule (1), previous vital signs (1), when desktop not available (1)	4 - first round assessment (1), check labs (1), when desktop not available (1), when in hallway (1)	1 - too much time and not reliable connection

Question 8: Problems encountered with the use of COW.

The following table shows the frequency that participants encountered problems with respective to the connectivity, battery, power-save mode, mobility, seating available and muscle fatigue when using a COW. Specific problems were also received. For example, connectivity problems were encountered at the beginning when the participants attempted to log on the system and in the middle of working at the computer when the connection was lost, batteries were found to wear down too quickly that they had to be plugged in after a short use (e.g 5 minutes), it took too long to reboot the system once the computer entered the power-save mode, the COWs were difficult to move along a crowded hallway, and the seating available did not provide back support, thus causing back pain and muscle fatigue.

	Connectivity	Battery	Power-save	Mobility	Seating	Muscle fatigue
ALWAYS	2	1	4	1	6	4
OFTEN	7	6	2	3	10	3
SOMETIMES	12	8	3	7	4	7
ONCE IN A WHILE	7	8	12	6	6	7
NEVER	0	3	3	9	2	6

Question 9: problems encountered when retrieving information in the EHR.

The table below shows the number of responses to each measurement when using the EHR software application. Additional comments include navigation between screens was tedious and time-consuming when accessing information, printing of information on paper was not available, and too much text information while preferring more graphical representation for trends while some comments were indeed related to the connectivity and battery problems described in Question 8.

	Problem retrieving information	Not sure where to look for information	Too much information	Information Layout
ALWAYS	14			
OFTEN	7		3	2
SOMETIMES	2	6	7	6
ONCE IN A WHILE		12	9	9
NEVER		6	6	9

Question 10: Preferred computer for preparing medication.

26 participants preferred to use a COW and 2 preferred to use a desktop when preparing medications for their patients (1 participant was a patient care manager who did not need to prepare medications). The reasons for preferring a COW include: the COWs could be moved to be placed beside the medication cart (22), they could check the medications at a COW (3), reduced medication errors (1), no desktops nearby (1), they could take a COW and med cart to patient room together (2), and workstations with desktops were crowded (1). Two participants preferred using a desktop computer to prepare medications because they did not find the COWs mobile and they could bring a med-cart beside a desktop so that no fear of computer freezing and power-save shut-off.

Question 11: Perception of social interaction in workplace.

All participants but one considered social interaction important in the workplace. They mostly engaged in casual communication during shift change inside the computer room and at meal breaks. They would also briefly mingle when they ran into other colleagues in hallways, at nursing station, around med-cart, and sometimes when they could both bring their COWs closer.

Appendix D. Focus Group Study

D.1 Recruitment Poster

Dear nurses,

we need your input!

We would like to ask the nurses on Unit 36 to participate in a focus group study to evaluate a technology for supporting information flow in nursing work. The design of this technology prototype was informed by several observational studies conducted on the ward.

This will be a great opportunity for you to try out our prototype and to comment on whether you think our design would help enhance your work and where we should revise in order to better support your work practices.

All nurses, including nursing students, are welcome to participate in our study. The study will last about an hour. We will hold each study session before your evening or night shifts, or after your day shift. To show our appreciation, we will provide the participants a nutritious meal that they can enjoy during their meal break or bring home.

To participate, you may sign up as a group of 4 or 5, or you may sign up individually.

Thank you so much for your support!

Charlotte Tang,

Your participation in the focus group study is only a one-time one-hour commitment.

We have scheduled the following focus group sessions for the next weekend (Nov 1 & 2). The times are picked so that nurses working evenings and nights just need to come to the ward an hour earlier and nurses stay for an hour longer on the day of their participation. Please check to see if one of them works for you.

If the following schedule does not work for you especially if you do not work on the next weekend, please contact Charlotte. We will set up focus groups on weekdays to suit your schedule.

Email: char.tang@ucalgary.ca
Cell: 403-123-7890

Nov 1	1:30 – 2:30pm
Nov 1	9:30 – 10:30pm
Nov 2	1:30 – 2:30pm
Nov 2	3:30 – 4:30pm
Nov 2	9:30 – 10:30pm

D.2 Ethics Approval

FACULTY OF MEDICINE | UNIVERSITY OF CALGARY

January 15, 2008

OFFICE OF MEDICAL BIOETHICS
Room 93, Heritage Medical Research Bldg
3330 Hospital Drive NW
Calgary, AB, Canada T2N 4N1
Telephone: (403) 220-7990
Fax: (403) 283-8524
Email: omb@ucalgary.ca

Dr. Sheelagh Carpendale
MS 680, Faculty of Computer Sciences
University of Calgary
Calgary, Alberta

Dear Dr. Carpendale:

RE: Information Flow: Observational Study of the Ward of the 21st Century in the Foothills Hospital

Ethics ID: 18936

Your request to modify the above-named protocol and consent form has been reviewed and approved.

I am pleased to advise you that it is permissible for you to use Amendment 1 to the protocol (dated December 13, 2007) as well as the revised Nurse Consent Form (Version 1.1, dated December 12, 2007), based on the information contained in your correspondence of December 13, 2007.

A progress report concerning this study is required annually, from the date of the original approval (2006-05-30).

The report should contain information concerning:

(i) the number of subjects recruited;
(ii) a description of any protocol modification;
(iii) any unusual and/or severe complications, adverse events or unanticipated problems involving risks to subjects or others, withdrawal of subjects from the research, or complaints about the research;
(iv) a summary of any recent literature, finding, or other relevant information, especially information about risks associated with the research;
(v) a copy of the current informed consent form;
(vi) the expected date of termination of this project.

Thank you for the attention, which I know you will bring to these matters.

Yours sincerely,

Glenys Godlovitch, BA(Hons), LLB. PhD
Chair, Conjoint Health Research Ethics Board

GG/jlm

c.c. Dr. Ken Barker (information) Ms. Charlotte Tang & Mr. Mark Hancock (Students)

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D.3 Consent Form

Title: Evaluating a Technology Design for Supporting Information Flow in Nursing Work.

Sponsors: Alberta Ingenuity Fund, iCore, Natural Science and Engineering Research Council

Investigators: Dr. Sheelagh Carpendale, Charlotte Tang, Dr. Saul Greenberg, Dr. Ron Wardell and Dr. Barry Baylis

This consent form is only part of the process of informed consent. It should give you the basic idea of what the study is about and what your participation will involve. If you would like more detail, please ask.

Purpose of the Study

We have conducted several observational studies on Unit 36 to investigate the information flow during nurses' shift changes. Based on the knowledge we gathered, we designed and developed a technology prototype to support the information flow. This focus group study aims to allow nurses to try out and evaluate this technology prototype and to comment on if it can help improve the information flow and where adjustments are needed to better support their work practices.

Description of the Study

Each focus group session will be videotaped for further analysis with participants' permission and carried out as listed below.

1. Each participant will be given a variety of stationary to create a template of the personal worksheets they desire for their nursing work. It is important to name the type of information and their spatial location and size on the template.
2. Participants in the focus group session will work together on a worksheet template that they agree upon.
3. Participants will try out our technology prototype setup.

4. Participants discuss and comment on the technology design.

Description of the Foreseeable Risks

There are no foreseeable risks in these activities.

Benefits to the subjects or others

The purpose of this study is to gather feedback from participants on the technology prototype setup that was designed based on our previous observational studies on Unit 36. Therefore your participation will help us identify issues of the technology design that require adjustments to (further) enhance the information flow, which will also benefit your work.

My Participation

Participation in this study is entirely voluntary. Should you feel uncomfortable, you may decide not to continue at any time during the study. We will not disclose this information to anyone.

Confidentiality of Research Records

Only the investigators of this study will have access to the raw information collected. Anonymity will be preserved in publications so that individual participants cannot be identified.

Compensation for Research-Related Injury

In the event that you suffer injury as a result of participating in this research, no compensation will be provided to you by the Alberta Ingenuity Fund, iCore, the Natural Sciences and Engineering Research Council, the University of Calgary, the Calgary Health Region or the Researchers. You still have all your legal rights. Nothing said in this consent form alters your right to seek damages.

Signatures

Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in the study and agree to participate. In no way does this waive your legal rights nor release the investigators, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

If you have further questions concerning matters related to this research, please contact:

Charlotte Tang, Dr. Sheelagh Carpendale, Dr. Saul Greenberg, Dr. Ron Wardell or Dr. Barry Baylis of University of Calgary, tangsh/sheelagh/saul@cpsc.ucalgary.ca, rwardell@telusplanet.net or baylis@ucalgary.ca.

If you have any questions or issues concerning your rights as a possible participant in this research, please contact the Associate Director, Internal Awards, Research Services, University of Calgary, at 220-3782.

____

Participants Name Signature and Date

____

Investigator/ Delegate's Name Signature and Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.
A signed copy of this consent form has been given to you to keep for your records and reference.

Appendix E. Co-author Permission

University of Waterloo

Systems Design Engineering
Faculty of Engineering

University of Waterloo
200 University Avenue West
Waterloo, Ontario, Canada
N2L 3G1

519-885-1211 or 519-888-4567 (automated)
Fax 519-746-4791

September 15, 2009

I, Stacey Scott, give Charlotte Tang permission to use co-authored work from our paper:

Tang, C., Carpendale, S. and Scott, S. (2010). InfoFlow Framework for Information Flow during Nursing Shift Change. International Journal of Human Computer Interaction - Special Issue on "Evaluating New Interactions in Healthcare: Challenges and Approaches" (conditionally accepted).

for Chapters 5 and 7 of her Ph.D. dissertation and to have this work microfilmed.

Sincerely,

Stacey D. Scott, Ph.D.
Assistant Professor, Systems Design Engineering

UNIVERSITY OF CALGARY

2500 University Drive NW, Calgary, Alberta, Canada T2N 1N4

September 11, 2009

I, Sheelagh Carpendale, give Charlotte Tang permission to use co-authored work from our papers:

Tang, C., Carpendale, S. and Scott, S. (2010). InfoFlow Framework for Information Flow during Nursing Shift Change. *International Journal of Human Computer Interaction - Special Issue on "Evaluating New Interactions in Healthcare: Challenges and Approaches"* (conditionally accepted).

Tang, C. and Carpendale, S. (2009). Supporting Nurses' Information Flow by Integrating Paper and Digital Charting. *Proceedings of the European Conference on Computer Supported Cooperative Work (ECSCW) 2009*, Springer London. Vienna, Austria, pp. 158-167.

Tang, C., Randell, R., Wilson, S. and Carpendale, S. (2009) A Tale of Two Studies: Evaluating New Technologies in Healthcare. *Workshop on Evaluating New Interactions in Healthcare, CHI 2009*, Boston MA, USA, April 3-9, 2009.

Tang, C. and Carpendale, S. (2009). A Mobile Voice Communication System in Medical Setting: Love it or Hate it? *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI) 2009*, ACM New York. Boston MA, USA, April 3-9, pp. 2041-2050.

Tang, C. and Carpendale, S. (2008). Support for Informal Information Use and its Formalization in Medical Work. *Proceedings of IEEE Conference on Computer Based Medical Systems 2008*, IEEE Computer Society Washington. Jyvaskyla, Finland, June 17-19, pp. 476-481.

Tang, C. and Carpendale, S. (2008). Evaluating the Deployment of a Mobile Technology in a Hospital Ward. *Proceedings of Computer Supported Cooperative Work 2008*, ACM New York. San Diego CA, USA, November 8-12, pp. 205-214.

Tang, C. and Carpendale, S. (2007). Impacts of Technology Deployment on Information Assembly and Disassembly during Shift Change. *Workshop on "Handover: Collaboration for Continuity of Work", ECSCW 2007.* Limerick, Ireland, Sept 24-28, 2007.

Tang, C. and Carpendale, S. (2007). An Observational Study on Information Flow during Nurses' Shift Change. *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI) 2007*, ACM New York. San Jose CA, USA, April 28-May 3, pp. 219-228.

for Chapters 3, 4, 5, 6, 7, 8, and 9 of her Ph.D. dissertation and to have this work microfilmed.

Sincerely,

Sheelagh Carpendale
Associate Professor

CITY UNIVERSITY LONDON

September 11, 2009

I, Rebecca Randell, give Charlotte Tang permission to use co-authored work from our workshop paper:

Tang, C., Randell, R., Wilson, S. and Carpendale, S. (2009) A Tale of Two Studies: Evaluating New Technologies in Healthcare. *Workshop on Evaluating New Interactions in Healthcare, CHI 2009*, Boston MA, USA, April 3-9, 2009.

for Chapters 4 and 9 of her Ph.D. dissertation and to have this work microfilmed.

Sincerely,

RRandell

Rebecca Randell

September 11, 2009

I, Stephanie Wilson, give Charlotte Tang permission to use co-authored work from our workshop paper:

Tang, C., Randell, R., Wilson, S. and Carpendale, S. (2009) A Tale of Two Studies: Evaluating New Technologies in Healthcare. *Workshop on Evaluating New Interactions in Healthcare, CHI 2009*, Boston MA, USA, April 3-9, 2009.

for Chapters 4 and 9 of her Ph.D. dissertation and to have this work microfilmed.

Sincerely,

Stephanie Wilson