

Iterative Design and Evaluation of a Software System for Nursing Applications in Healthcare

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ABSTRACT

Iterative Design and Evaluation of a Software System for Nursing Applications in Healthcare

Ajay Narasimhadevara

The need to promote the application of computers in the healthcare industry, particularly through the adoption in Clinical Information Systems (CIS), is more important now than ever before. As the healthcare industry faces a big deficiency in Information and Communication Technology (ICT) applications, we believe that system developers have to follow appropriate methodologies so that the resulting software product in this application domain could be considered easy, both to learn and use, by direct end-users while remaining acceptable to all involved stakeholders and their dynamic needs. With this in mind, in this thesis, we have combined the use of workflow modeling, agile software development through eXtreme Programming (XP) and the principles and practices from User-Centered Design (UCD) to develop a component of CIS; namely, a nurses' module. The workflow model of the various processes in the organ transplant ward of a typical large hospital was acquired. From this, the *Nursing Process* was developed as an application exercise. The resulting software product called Nurse User Interface (NUI) was field-tested by several healthcare providers in a "real-life" work environment. The field-test revealed that our software was well received by the healthcare providers and helped provide an opportunity to save time with the nursing documentation activity. The systematic usability evaluation of the developed software product (NUI) was conducted and the resulting scores indicate the "goodness" of the product with regard to the quality of use parameters of *Efficiency*, *Affect*, *Helpfulness*, *Control* and *Learnability*. The combined use of XP and UCD along with the close involvement of the healthcare professionals, or end-users, in the iterative development and refinement of the intended software product seems to have made a noticeable impact. However, for such an approach to be practicable, we need the cooperation and support of end-users throughout the design process.

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Lastly, to my parents and my entire family, thanks for being my constant source of encouragement. Without the comfort of your unconditional support, none of this would have been possible.

— Ajay Narasimhadevara

Dedication

This thesis is dedicated to the memory of my late aunt - Bhanumati Panchmatia, and my late grandfather - Janardana Sastry Narasimhadevara, both of whom passed away while I was in the process of completing my research.

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Nomenclature

AIS	-	Administrative Information Systems
AO	-	Action-Oriented (Activity)
CIS	-	Clinical Information Systems
CPOE	-	Computerized Physician Order Entry
DFP	-	Design Focus Point
EPR	-	Electronic Patient Record
FO	-	Information-Oriented (Activity)
GUI	-	Graphical User Interface
HCP	-	Healthcare Provider
ICT	-	Information and Communication Technology
IOM	-	Institute of Medicine
IS	-	Information Systems
IT	-	Information Technology
LIW	-	Least Interruption to Workflow
MVC	-	Model-View-Controller
NUI	-	Nurse User Interface
PCA	-	Patient Care Associate
PD	-	Participatory Design
PIU	-	Panel Interaction Unit
RAD	-	Rapid Application Development
RUP	-	Rational Unified Process
SUMI	-	Software Usability Measurement Inventory
UC	-	Unit Coordinator
UCD	-	User-Centered Design
UI	-	User Interface
UML	-	Unified Modeling Language
WA	-	Work-Allocation
WfMS	-	Workflow Management System
XP	-	Extreme Programming

Chapter 1

Introduction

Information Systems (IS) or computer-based support has become an essential part of today's work environment. They provide unparalleled support for communication and computational power that allows for growth and improvement in the way work gets done. In fact, IS have become such an important resource that it is widely believed they are necessary for organizations to survive [1–4]. Thanks to continuing technological advances, highlighted by the reduced cost of storage and the inception of high-performance computing, the application of IS and its benefits continue to grow in many sectors of government, business, manufacturing, service industries, and the public sector at large. However, despite this increased emergence of IS, the healthcare industry continues to benefit much less with this technological advance than other sectors.

As has been the case for the past decade, the healthcare industry continues to be among the fastest growing in the world [5]. Its application has roots in both the public and private sectors and it is one of the world's largest service sectors. In fact, today it is one of the most important sectors in the US economy and is expected to continue its growth at a rate of 30% until 2012 [6, 7]. Furthermore, of the fastest growing occupations in the next half decade, 10 of the top 20 are expected to be related to some form of health services. Alongside this tremendous growth of the healthcare industry, the last two decades has also exhibited a phenomenal growth in the knowledge base of medicine [8,

9]. As this pace of knowledge discovery in the medical field is expected to continue accelerating in the coming years, it has made the traditional delivery of patient care based solely on human memory and manual practices increasingly unacceptable [10–13]. As a result, there is a need to change the way we store, share, and process knowledge related to healthcare in a form that is more amenable for IS support. This need has brought about the adoption of computer-based IS in several hospitals.

For almost three decades, computer-support systems have been implemented and incorporated in healthcare environments. These systems are divided into two broad categories: Administrative Information Systems (AIS) and Clinical Information Systems (CIS). AIS deal mostly with billing, accounting, and hospital administration. CIS, on the other hand, have the task of integrating all areas and functions of healthcare delivery to patients. Networking, computerized patient records, data gathering and maintenance form the core of these systems. CIS is then aptly characterized by the collection, retrieval, processing, storing and the distribution of information to allow clinical decision making to be driven by the need for point-of-care information access by providers in real-time [14]. Although today the development of AIS predates CIS, significantly more investment dollars and resources are being infused into CIS endeavors. The reason for this apparent discrepancy is that CIS is believed to hold more power in attempting to radically improve the practice of medicine. This improvement in overall patient care is anticipated to result in the reduction of medical errors and costs along with improved quality of service.

The healthcare industry has been met with a growing number of software companies and products for CIS since the 1990s. Despite this considerable interest, the landmark report *To Err is Human: Building a Safer Health System* [15] released by the Institute of Medicine (IOM) in 1999 indicates that the penetration of IS into the clinical aspect of medicine is totally inadequate. The report points out this lack of adopting appropriate computer support systems to improve patient care is annually causing more than 1 million injuries and 98,000 deaths in the United States alone because of medical error. Since then, recent studies indicate that today there has been a modest improvement in the penetration rate of computer support systems in our hospitals. Studies as recent as 2002 reveal that although the penetration rate of AIS is 66%, CIS has a penetration rate of only 5–15% [16–18]. This distressing lack of CIS penetration in hospitals suggests that a significant portion of exploratory work and financial investments have proved unrewarding in an attempt to increase the exposure of computer support in hospitals. In light of this, our 21st century medical system continues to be governed by a paper-based record system and continues to be heavily dependent on a commitment to the memory of healthcare professionals. Furthermore, as the demand for information intensifies, it will continue to cripple the current system by making it increasingly less viable and could result in increased errors and further degradation in the quality of patient care.

With paper-based hospital IS continuing to present high failure rates, and concerns regarding the quality of patient care continuing to escalate; addressing the need to promote increased use of IS in the delivery of care is becoming indispensable. Integrated IS in healthcare delivery can provide significant improvement in preventive health

services, disease management, and patient safety [10, 19]. It has also been demonstrated that a well structured CIS provides healthcare practitioners access to timely and comprehensive patient information, which leads to improved care [20]. This significant improvement in the quality of the health service promised by a “well-matched” IS exposes the inability of our current manual systems scaling up to the increased demands from all directions of the healthcare marketplace. There is also another angle to this need — the emergence of a new medical care paradigm known as *Evidence-Based Medicine* needs extensive record keeping [21]. This new medical movement applies additional rigorous data and knowledge driven scientific methods to patient care giving. As such, in order to support this movement, there has to be a foreseeable means whereby this evidence information is readily available at the point of care in a form that facilitates timely retrieval, interpretation and application [22].

In this thesis, we have taken a practical step towards addressing the issue of IS in healthcare by creating and executing an applied research project. We set two goals in this project: (1) apply a combination of existing software development methodologies to a manageable size “real-life” problem in a hospital environment; and (2) after understanding and analyzing the critical issues involved in the selected problem, develop a software product that is usable in practice, and evaluate its use through a “real-world” field-test in a hospital setting. In order to achieve these goals, we have employed a combination of software development methods from workflow modeling, User-Centered Design (UCD), and agile software development to engineer a software product which we have called NUI in this thesis. This resulted in a product-driven design effort that spent

much effort in understanding and documenting user requirements as extracted from the analysis of the issues involved in our manageable healthcare sub-problem. This was made possible by finding enthusiastic and willing healthcare volunteers from a large metropolitan hospital to participate with us both in the design and in the evaluation of the NUI. In establishing this close liaison with our healthcare volunteers, we were able to develop the completed NUI software product in a span of 15 months. Contrary to many other large scale CIS deployments (including one such endeavor underway at this same metropolitan hospital), we employed an approach in which the process discovery was made through iterative requirement elicitation. Throughout our work, different nurse practitioners were involved in requirements definition, prototyping, and evaluation in every iteration of the development. Through this approach, we succeeded in instilling a sense of trust with both the end-users and hospital administration. This earned trust enabled us to subsequently perform a field-test of our software in this same hospital setting. Although this approach resulted in a usable product, its scalability to a large scale system needs further investigation.

Our core contribution in this thesis is then the application of a select combination of process modeling, UCD, and agile software development methods to the complex process of nursing in the delivery of patient care. In doing so, based on many facets of failure of currently deployed systems, we propose the development of a system that minimizes departure from currently well-refined clinical practices. This underlying constraint will help ensure that developed measures of computer support can manage unpredictability in the work practice and remain aligned to existing and well-accepted clinical practices. In

attempting to meet this objective, we developed the NUI software product using our combination of software development methods and conducted a field-test in a clinical environment to demonstrate both the viability and feasibility of our approach. Although our work is limited to the development and experiences with the NUI, the approach has proven practicable and we believe that these ideals embody a design strategy for complex work processes that can be of interest to system designers.

The rest of the thesis is organized as follows: Chapter 2 discusses various issues in CIS to provide a background. Chapter 3 provides discussions on modeling the healthcare workflow, in the context of the problem selected, that was used for requirements understanding. Chapter 4 presents an overview of the software design methodology employed and its application in the development of the NUI product. Chapter 5 describes the challenges faced in real-life field-testing the NUI in a continuously operating hospital environment and presents the evaluation results of the NUI software product. Finally, Chapter 6 presents a summary of this thesis and recommendations for future work.

Chapter 2

An Overview of Related Work

In this chapter, we review some of the research efforts that have focused on understanding the underlying issues involved in the integration of IS in healthcare. This discussion begins by reviewing some of the multifaceted reasons for the slow penetration of Information Technology (IT) in healthcare; and then considers the design implications of migrating from an existing paper-based to computer support systems in a hospital environment. We then use this knowledge to substantiate the emerging design paradigm of workflow modeling for developing computer applications in healthcare. In addition, we also introduce principles from the design philosophies of User-Centered Design (UCD) and agile software development which we argue are better suited to developing computer support for the healthcare system.

2.1 Barriers and Resistance Faced in CIS

Over the past decade, there has been an increasing demand for IT in business work processes. However, this high demand has led to the development of many unsuccessful and poorly developed systems. These systems performed badly, were difficult to use, or failed to provide any functional benefit to the end user [23–25]. Despite these initial shortcomings, advancements in software engineering techniques have provided the necessary means to ensure that these systems are better able to cater to the needs of users.

Yet, there continues to be barriers that prevent the benefits of IT from having a positive and noticeable impact on healthcare systems [24, 26, 27]. There exists no shortage of research attempting to explain why such systems are being met with resistance by the medical community [24, 26, 28]. In fact, research into this domain has resulted in the field of *Medical Informatics* that addresses such issues [29]. After the surfacing of the landmark 1999 IOM report [15] summarizing the general reluctance towards IT adoption, there has been a pressing need to understand why healthcare practitioners are choosing to not adopt. The vast quantities of published works that exist today in this regard have some consistent findings.

One core issue that is often cited as a barrier that has challenged IS adoption in healthcare is diversity, decision-making in the face of incomplete information, and human-driven adaptiveness in healthcare systems [30]. The development of IS requires a structured approach to problem solving and is based on rigid structures; meanwhile, modern healthcare delivery is considered as a complex adaptive system that exhibits uncertainty in predicting the emergent behavior of the system. This self-adaptation of the invariably complex care process is believed to be a key issue that differentiates the health care system from all other lines of industry. With a large number of interacting parts, interactive complexity, and evolving through self-organization, healthcare provides a domain where classic software engineering approaches are insufficient and not easily applicable to meet health IT demands. Furthermore, with many different actors in the care process (patients, doctors, nurses, etc.) each of their interactions is influenced by a different clinical scenario as well as each individual's role, training, and personality.

Consequently, there has been major difficulty in capturing an accurate understanding of the needs of the medical community [24, 30, 31].

The slow acceptance of CIS has been a recurring theme throughout the 1990s and a high rate of failure of IT projects has not been uncommon [27, 32]. Although these failed development efforts have proved to be lost opportunities and wastes in terms of financial and human resources, they have played an important role in helping researchers in the design community identify core issues involved for a successful implementation of CIS. There are two major criteria that today are commonly identified with the success cases of CIS: (1) user involvement in systems development and (2) top management support in deployment [33]. Lack of proper user involvement is one of the bigger shortcomings that to date has prohibited IS expansion [24, 26]. This relates especially to the inaccurate understanding of end-user needs. This can be attributed to many reasons including: insufficient communication, inability of users to express their requirements or the lack of a common ground between end-users and designers [34]. This failure to properly find a mechanism to capture the needs of end-users in the design of IS has then led to diminished acceptance of these systems. This clearly illustrates that when the deployed IS differs from the traditional practice routines, it is unlikely to be accepted by the medical community [26]. On the other hand, the support of top management is important since a lack of support would prevent financial assistance. At this level, acceptance of the system is not based on usability but rather on ensuring that the system provides a noticeable return on investment and is consistent with the IT goals of the healthcare organization.

Besides the aforementioned issues of user involvement, management support and lack of a suitable engineering process, no less than 50 other factors for project failure have been identified through various case studies as reported in [24, 35]. According to a 2004 survey of key healthcare trends [36], there exist 10 significant barriers in implementing healthcare IT as listed in Table 2.1.

IT Barrier	2004 Respondents	2003 Respondents
Lack of Financial Support	23%	23%
Vendor's Inability to Effectively Deliver Product	14%	19%
Proving IT Quantifiable Benefits/ROI	13%	13%
Difficulty Achieving End-User Acceptance	11%	10%
Lack of Staffing Resources	10%	12%
Lack of Clinical Leadership	9%	N/A
Lack of Top Management Support	7%	5%
Lack of Common Data Standards	3%	5%
Lack of Strategic IT Plan	3%	5%
Other/Don't Know	7%	9%

Table 2.1 – Significant barriers to implementing IT in healthcare

In order to overcome the continuing widespread rejection of these systems, healthcare pioneers are realizing that it is becoming increasingly important to understand the social and organizational issues in the healthcare domain in addition to technical ones [37–39]. It is strongly believed that this consideration, prior to development, of how these IS will affect routine practice patterns and professional relations will lead to systems better tuned to the needs of healthcare providers. This will ensure that the system meets existing clinical workflows and is better suited to meet the needs than otherwise [40, 41]. This is substantial since researchers have found that rash modifications to well-defined medical work practices could be detrimental [42]. Therefore, a suitable CIS needs to appeal to all stakeholders while it simultaneously must ensure that the system takes into consideration different interactions characterized by clinical scenarios and an individual's role, training,

and personality. The result is a system that can respond adequately and effectively towards resolving the continued deficient state of patient safety.

2.2 The Paper-Based Healthcare Information System

Despite all its shortcomings, the paper-based medical recordkeeping practice and manual methods of information tracking work. In fact, with CIS deployments still infrequent, the majority of healthcare venues continue to rely on their manual paper-based system as a primary form of communication. Although this manual recordkeeping paradigm has been proven to work and has undergone many refinements over many decades, it has become increasingly less viable and it has come to a point where it is becoming incapable of supporting the growing demands of healthcare [19, 43].

The initial inception of the manual paper-based IS in healthcare predates to the 19th century [11]. At that time, it arose as a highly personalized lab notebook that physicians used to record observations about their patients. Today, a century and several technological revolutions later, we find ourselves still supporting this antiquated design paradigm for data accumulation. Moreover, not only is this paper-based approach more labor intensive and fraught with opportunities for errors through lost and unreadable documentation, but it is also impeding the progress of clinical research. The Electronic Patient Record (EPR), which forms the basis for CIS, attempts to address this issue by promising a paperless computer-based clinical record. It offers such basic advantages as enhanced storage and retrieval functionality to quality health information in addition to providing instantaneous and multi-location access to potentially geographically dispersed

information. With the added potential to greatly enhance clinical trials and provide integrated decision support, the IOM's report on computer-based patient records [44] argues that hospitals should quickly adopt such automated support for medical records. Although many merits of paper-based hospital IS are well articulated in [45], this system fulfills two major functions that are considered crucial for current medical practices [46, 47]:

1. The first function is providing a structured context for data accumulation. The paper-based hospital IS not only serves as passive data repository but also provides a specific structure and context for data accumulation that enhances information sharing.
2. The second function, which is obscure to those outside of the healthcare system, is that these paper-based hospital forms provide a mechanism to structure and sequence the workflow among various providers of care. These hard copy forms play the important role of communication to coordinate the activities and events at various locations and times in the hospital. This discovery has led to the general belief that the computer-based medical record is best viewed not as an object but rather as a set of processes that an organization must put into place, supported by technology [11].

To date, many automation efforts have been transfixed on providing a paperless information system by attempting to improve the data gathering process. This failure to understand the deeper values of paper-based order forms modeling the work relationship of healthcare providers has provided a substantial deviation from standard work practices

that have warranted the widespread rejection of many CIS opportunities [45]. It is therefore becoming increasingly important to model the environment of the current healthcare practice in order to better understand the role of paper-based information flow in that organization.

2.3 Workflow Modeling

Healthcare activities are fundamentally human-centered activities. As a result, their apprehension requires the understanding of the coordination between actors. One can study this through analysis of the scenarios and the data exchanged between actors during clinical processes [48]. This realization has created increased pressure to uncover a design paradigm for IS development in healthcare that can handle such a circumstance. Within the last several years, an abundance of research suggests that workflow modeling can help to address complexity in the healthcare process by overcoming the current lack of alignment of health IS to healthcare processes [49]. Furthermore, it is believed that it can provide the basis of an effective and logical mechanism that can be used to design usable, effective, and acceptable IS for the healthcare system [48, 49]. Defined formally, workflow modeling is the ability to provide a foundation for the definition of step-by-step processes that are required to execute a work process [50]. A process model, in turn, is a set of coordinated and interacting processes of the same nature that are grouped together [51]. While a workflow is real and it exists, a process model is often used as an abstraction mechanism of objects to help address workflow complexity. Due to their vast appeal, process models are classified into several broad categories based on their application [51, 52]. For the purposes of our work in healthcare we focus our attention

towards activity-oriented process models that are related sets of activities conducted for the specific purpose of reaching a goal [53].

The general approach of employing workflow modeling to the healthcare sector has received significant backing since its initial proposal as a viable approach to the development of healthcare IS. With the need for a clinical IS that behaves *process-oriented* rather than purely functionally oriented to meet the needs of healthcare, it is believed that workflows are well suited to the highly “messy” and “ad-hoc” nature of healthcare work [54, 55]. Employing workflow technology to support clinical processes can ensure that an IS is designed to offer the right task support, at the right point in time, to the right person along with the right information needed to perform these tasks. This approach effectively emphasizes modeling actor responsibilities and information flows in an overall attempt to better understand the organization and capture a complete and systematic view of hospital activities. In the end, this exercise of modeling the complex human care activities of healthcare can lead to specific user requirements needed for the development of process-oriented IS in healthcare [56].

Clinical processes are renowned as complex care activities that require a large degree of communication and cooperation among healthcare providers [45]. These processes, which undergo frequent change, are rarely completely predictable. Consequently, they require a suitable specification framework that is in tune with the flexible nature of these processes [57]. Unlike traditional functionally-oriented systems that remain stable for long periods of time, process-oriented IS have the drawback that they need to be

modified whenever the process in the underlying real world changes. In healthcare, for instance, this happens quite frequently. When a change is needed, a process-oriented IS must ensure that it can easily evolve to the organization's new structures quickly and at a reasonable cost [42, 58].

The separation of flow structure from the implementation of application software has already been practiced in several existing solutions in the form of Workflow Management Systems (WfMS) [59, 60]. However, these WfMS are all primarily designed to support well-structured processes that show little variation in their task structure. This underlying assumption that all aspects of a process and all tasks are known in advance makes these systems ill suited to healthcare [34]. In the care-giving process, there is a need to adapt to the individual needs of patients, hospital wards and healthcare professionals. Exceptions, unexpected events and the immediate need to care for the patient create the primary need for coordination and consequently provide the greatest information processing burden on the organization [61]. While some tasks can be predicted in advance, others have to be dynamically scheduled based on the individual patient and their state of health. Although it is clearly impossible to pre-model all the possible task sequences and all exceptions in clinical processes, failure to account for this has led to initial developments of many rigid template-defined workflows [56, 60]. This becomes unacceptable because when an additional "measure" in a process is needed, the process-oriented IS impedes a healthcare provider from performing this desired measure. Consequently, addressing the need of providing a suitable process-oriented IS in an environment that contains processes of

different complexities and durations starts with building a systematic view of hospital activities [42].

In the end, although an information-processing framework can be used to model routine medical protocols, it is not sufficiently expressive to capture all protocol types, or the contingent nature of medical care [61]. There is then a need for process-oriented IS that represents how work is accomplished, will elicit the specifics and generics of requirements and can be modeled and validated through intuitive model-based interactions with users. With the cooperation between organizational units and medical personnel being a vital task with repetitive but non-trivial character, we will use the science of workflow modeling to help build a process-oriented IS for healthcare.

2.4 Agile Software Development

Agile software development [62] is a set of methodologies for designing software that have been proven to be effective in dealing with projects that have unclear or rapidly changing requirements. It is a fast and lightweight software development process that promotes emphasis on teamwork, customer involvement, and the frequent creation of small working pieces of the total system in order to use iteration and feedback as primary control mechanisms [63]. In doing so, this development philosophy promises to achieve higher customer satisfaction, lower defect rates, and faster development times while providing a solution to rapidly changing requirements [64, 65].

Although iterative and incremental development, which forms the basic school of thought for agile software development, is rooted as far back as the mid-1950s, agile software development as we know it today surfaced much more recently [66]. The roots of agile software development date back to the mid 1990s as a partial response against “flexiweight” methods like RUP (Rational Unified Process) [62]. At the time, these methods were seen as bureaucratic, slow, demeaning, and contradicted the ways that software engineers actually work. The interest towards more “lightweight” methods led prominent members of the design community towards agile methods and eventually towards the formation of the non-profit *Agile Alliance* that promotes agile development.

The *Agile Manifesto* [67], developed in 2001 by the *Agile Alliance*, is today still widely regarded as the universal definition of agility. It was written by a group of industry experts in an attempt to outline values and principles that allow software to be developed quickly and be able to respond to change. The manifesto is based on four core values:

1. Individuals and interactions over processes and tools
2. Working software over comprehensive documentation
3. Customer collaboration over contract negotiation
4. Responding to change over following a plan.

We highlight the most visible aspects of agile development from the manifesto [67] as the following:

- Developing software in short iterations

Agile methods attempt to minimize risk by developing software in short timeframes, called iterations, which vary in length but typically last from one to six-weeks. Each of these iterations resembles its own software project and includes all tasks necessary to complete the software upgrade increment.

- Interactive communication

Agile methods emphasize real-time face-to-face (people-oriented) communication and teamwork between developers and clients over institutionalized processes, development tools, and documentation.

- Emphasize working software

Agile methods emphasize working software as the primary measure of progress. As such, with short iteration intervals, an agile process should be able to release tested working software at frequent intervals.

A comprehensive list characterizing agile software processes would also include [68]:

- Modularity on development process levels
- Parsimony in development process removes all unnecessary activities
- Adaptive with possible emergent new risks
- Collaborative working-style

According to recent estimates by a United States analyst firm [69], only 10% of corporate IT organizations currently use agile methodologies. However, they suspect that up to 25% of corporations are currently exploring some form of agile process. Although there continues to be newfound enthusiasm in the approach, it has also received its fair share of criticism [65, 70, 71]. The overwhelming sentiment is that agile methods are excessively extreme and are nothing more than undisciplined “hacking”. There is also significant belief that it requires too much cultural change to adopt and that it fails to provide an adequate level of structure and documentation. The main issue of contention is that instead of considering agile methods as adaptive, flexible, and less formal approaches, they are consistently being regarded as unplanned or undisciplined approaches.

Today there exist many agile software development methodologies. Although these different methodologies vary in several dimensions, according to one proposed definition [64], they all must exhibit incremental, cooperative, straightforward, and adaptive characteristics. Some of the well-known ones include: eXtreme Programming (XP) [72], Scrum [73], Adaptive Software Development (ASD) [74], Crystal Clean and other Crystal Methodologies [62], DSDM [75] and Feature Driven Development [76]. Of these, XP is by far the most prominent agile methodology.

Extreme Programming (XP)

XP was developed by Kent Beck, Ward Cunningham and Ron Jeffries. It evolved from problems caused by traditional development methods [72] and started as an “opportunity to get the job done” [77]. After several successful trials [78, 79], the principles and practices observed were theorized into the XP methodology. Since XP is still a

contemporary development methodology, it continues to be fine tuned as it is incorporated and applied in many different disciplines. However, as its actual application may vary, its beliefs have been captured into the following four values that encompass the XP design strategy [72].

1. Simplicity
2. Feedback
3. Communication
4. Courage

Although twelve practices have been identified and associated with XP development [72], they are rarely all observed within in the same development project. As such, we identify the core practices of XP as the following:

1. The planning game

Close interaction between the customer and the programmers. The programmers estimate the required effort and the customer decides about the scope and timing of releases.

2. Small releases

A simple system is produced rapidly. New versions can be released daily but at least once every two to three months.

3. Metaphor

The system is defined by a set of metaphors between the customer and the programmers. This “shared story” guides all development by describing how the system works.

4. Simple design

The emphasis is on designing the simplest possible solution that has the capacity to be implemented at the moment. Unnecessary complexity and extra code are immediately removed.

5. Testing

Software development is test driven. Unit tests are implemented before the code and are run continuously. Customers write the functional tests.

6. Re-factoring

The system is restructured by removing duplication, improving communication, simplifying, and adding flexibility.

7. Continuous integration

A new piece of code is integrated into the code base as soon as it is ready. All tests are run and they have to be passed for the changes in the code to be accepted.

With this in mind, researchers point out that the virtue of agile methods like XP is not in the actual practices but rather in the recognition of people as the primary drivers of

project success [63]. In fact, Beck [72] points out that XP is nothing but a collection of ideas and practices from already existing methodologies.

Applying Agile Software Development to Healthcare

Researchers have found that due to the nature of healthcare work, many management models for software engineering are not well suited for this domain [34, 49]. These traditional models are unable to cope with the continually changing requirements that can occur throughout the design process. Furthermore, it is increasingly believed that current traditional models are ill-suited for Rapid Application Development (RAD) and a new quality software process is needed for the healthcare sector [80]. We believe that employing certain select principles from an agile development methodology like XP would be beneficial. This approach would provide a suitable middle ground for healthcare IS development by providing a framework for design between software development without any meaningful process and software development using too formal a process. This would also help overcome the major hurdle of limited user involvement that currently plagues most CIS projects.

Consequently, we wanted to investigate whether applying the focal aspects of simplicity and speed of agile methods through XP could bring significant benefits in a product developed for use in healthcare. With core principles that include delivering fast software, collecting feedback, and reacting to received information through a commitment to communication and teamwork, we believe that such an approach could be extremely beneficial.

2.5 User-Centered Design (UCD)

UCD [81] is both a design philosophy and a process which addresses the needs and wants of end-users in the design process. Design focuses on people, their work, their environment, and how technology can be best deployed and designed to support them [82]. This design approach is characterized by an iterative design process along with comprehensive evaluations. Designers are responsible to foresee how users are likely to use a system as well as test the validity of these assumptions to real world tests with end-users. Ethnographic studies are often used in UCD projects as a mechanism to better understand this environment where the user will interact with the system.

UCD first emerged in the 1980s as a methodology that addresses techniques for human-computer interaction [83]. It was first rooted into the cognitive processes of users as predictable and quantifiable but has since evolved to involve constant feedback and conversation between users and designers that is based on the interface experiences that users want to have with the system. UCD continues to be a modern and widely practiced design philosophy [81] which maintains that users must take center stage in the design of any computer system. In fact, UCD has matured and given way to an international ISO standard [84] that defines general steps for including human-centered activities in the life cycle of software development.

Participatory Design

Today, many approaches exist that adopt UCD principles. One of the more popular ones is Participatory Design (PD). PD [85] is a cooperative design approach that empowers

users in the design process by arguing that they have the right to be involved in the design of systems they subsequently use [86]. It spans a rich diversity of theories, practices, analyses, and actions which emphasize that “end-users are prime sources of innovation and that systems should be viewed as networks of people, practices, and technology embedded in organizations” [85]. Although PD has a sound basis, practicing it does involve significant challenges [82]. One of these challenges involves the additional effort required to guide users in the design process and to ensure that the political climate is suitable for PD.

Applying PD to Healthcare

Despite the advancements in PD, few designers have attempted to use this approach to meet the needs of healthcare [87]. Of those few that have undertaken involving PD practices to develop a healthcare IS [88–90], many have uncovered several implications. These include determining an appropriate form of participation to be used as well as ensuring that non-designers are introduced to design objectives, processes, and ideologies of PD. It is reasoned that this will help users to simultaneously understand societal constraints and influence them accordingly in the development process.

With the cooperation from nurse volunteers, physicians, and members of administration that we fostered; we believe that our situation for applying the UCD/PD approach can be highly favorable.

2.6 Existing CIS Systems

There exists no shortage of commercial vendors that currently provide CIS solutions [91–93]. Through our research, we had the opportunity to meet with users of two of these systems¹ and gain some insight into their attitude towards these products. Their overwhelming sentiment revealed to us that they were impressed with the capabilities and applicability of computers in their work but they felt these systems were still far from an ideal fit for their work practice. Instead of systems that helped them to do their work, they felt that they were frequently the ones adapting to the system. This constant need to acclimatize to the system made them feel as if they had no voice in the computer system's development but had to continue adapting their workflow. However, with a lack of viable software alternatives, they were being forced into using these products by upper-level management. Consequently, we noticed that there was considerable backlash in the way each nurse and physician used the system to adapt to their working needs. In addition, from a system design point of view, we felt that these systems left much to be desired in terms of usability and flexibility. Although users were trained to interact with the system in a particular way, we observed these interactions were far from optimized and involved a series of challenging movements and clicks to achieve desired tasks. On the other hand, despite some of their many limitations, these systems were impressive in being able to offer such a technologically rich feature as a built-in voice capability.

¹ OTTR[91] and OACIS[92]

2.7 Summary

In order to provide the motivation for our research, in this chapter we started by performing a survey of published works in the domain of medical informatics. Due to the abundance of existing research, we synthesized these results into a set of key themes that explain the current state of IS in healthcare with regard to our problem domain. From this exercise, we learned that the lack of considering social and organizational issues in the design of healthcare IS and the inability to understand the paper-based order forms in modeling the work relationship of healthcare providers are two major issues that continue to prevent the acceptance of CIS. Furthermore, we learned that clinical processes are complex activities and should be met with a process-oriented IS that can accurately capture the nature of medical work. Following this literature review, we introduced the design philosophies of UCD and XP that we will be using in our design process. Finally, we presented the details of our interviews with users of two other leading commercial CIS vendors.

Chapter 3

Workflow Modeling

In the previous chapter, we discussed the role that workflow modeling can play in the development and evolution of hospital IS. In this chapter, we use this process-oriented view as a preamble to the design of a software subsystem for an organ transplant ward of a large metropolitan hospital.

3.1 The Nursing Activity for Organ Transplant Patients

Organ transplantation in healthcare is a well-established and often lifesaving treatment for patients with organ failure. It is a highly data intensive medical discipline that involves a series of specialized practices and protocols. Data is being generated by several actors in this healthcare process at different times and at different points of care [94]. Three distinct stages are identified with organ transplant: pre-transplant care as an outpatient or in the hospital, transplant and recovery in the hospital, and post-transplant follow-up for the lifetime of the patient at the transplant clinic. With such an elaborate and complex care process that is characterized by the interaction of multiple actors, transplant patients are generators of large amounts of data.

For the purposes of our study, we selected the goal of supporting the activities of nurses at this organ transplant ward. The decision to direct our design experience towards

nursing activities was due to our limitations on both time and cost. These underlying restrictions made it impossible to provide support for all interacting processes that we found to take place in this ward. As such, we chose a manageable and suitable sub-project towards addressing IS in healthcare by implementing a structured process-oriented IS to support the nursing work environment. In fact, our decision for selecting this sub-project is based on many reasons: (1) nurses form the largest employee base in hospitals and their attitude towards computerization is believed to largely dictate success/failure [95], (2) we had the opportunity to observe this category of actors and the coordination of their actions in the hospital setting over a six-week period in 2003-2004, (3) we found willing and experienced nurse volunteers to participate in our experimental project both in the design phase and in the user-evaluation phase, (4) this sub-project provided us with several challenges including its complex interdependency with other possible subsystems of a typical CIS, and (5) currently there is no such subsystem in use for nurses at this hospital; although introduction of a CIS in a hospital-wide manner is in progress. With these reasons in mind, we believe that this sub-project provides an avenue for significant cost-benefits and a practical opportunity towards addressing the issue of IS in healthcare.

3.2 Current Context of the Organ Transplant Ward

At this time, the transplant ward of this large hospital currently relies on a paper-based system as its primary form of communication. This paper-based system has been proven to work and has been refined over many years. Thus, it has its own merits and people have been well trained to use this system. The manual record system is characterized by

the use of a number of different paper forms to record information and to coordinate activities among healthcare professionals. However, this transplant ward does not rely exclusively on this manual information system as some activities in the ward incorporate varying degrees of computer-support. This includes an automated admission procedure affiliated with the AIS and the existence of a transplant database that is based on an Electronic Patient Record (EPR). This database stores important patient data that includes, among other things: patient demographic information, transplant type (liver, kidney, pancreas, or combinations), patient's time series data of blood test results (for each patient), and current medications. However, it should be noted that the current application of this database is very much limited. In fact, nurses in the ward do not even interact directly with this database. In addition to the aforementioned form-flow and the transplant database, data in this organ transplant ward is also communicated using much less structured media that includes hand-written notes, verbal communication, nursing notes, and phone communication.

In this transplant ward, nurses are the major consumers of this manually recorded information. They consistently deal with a multitude of specialized forms to record data in order to communicate it with other healthcare professionals. Due to the acute care required for transplant patients, nurses spend non-trivial amounts of time generating, accessing, and disseminating information. This constant shifting of their priority between physically nursing the patients and performing information-oriented activities, as the situation demands, is then an inevitable part of their work. This is abstractly represented in Figure 3.1.

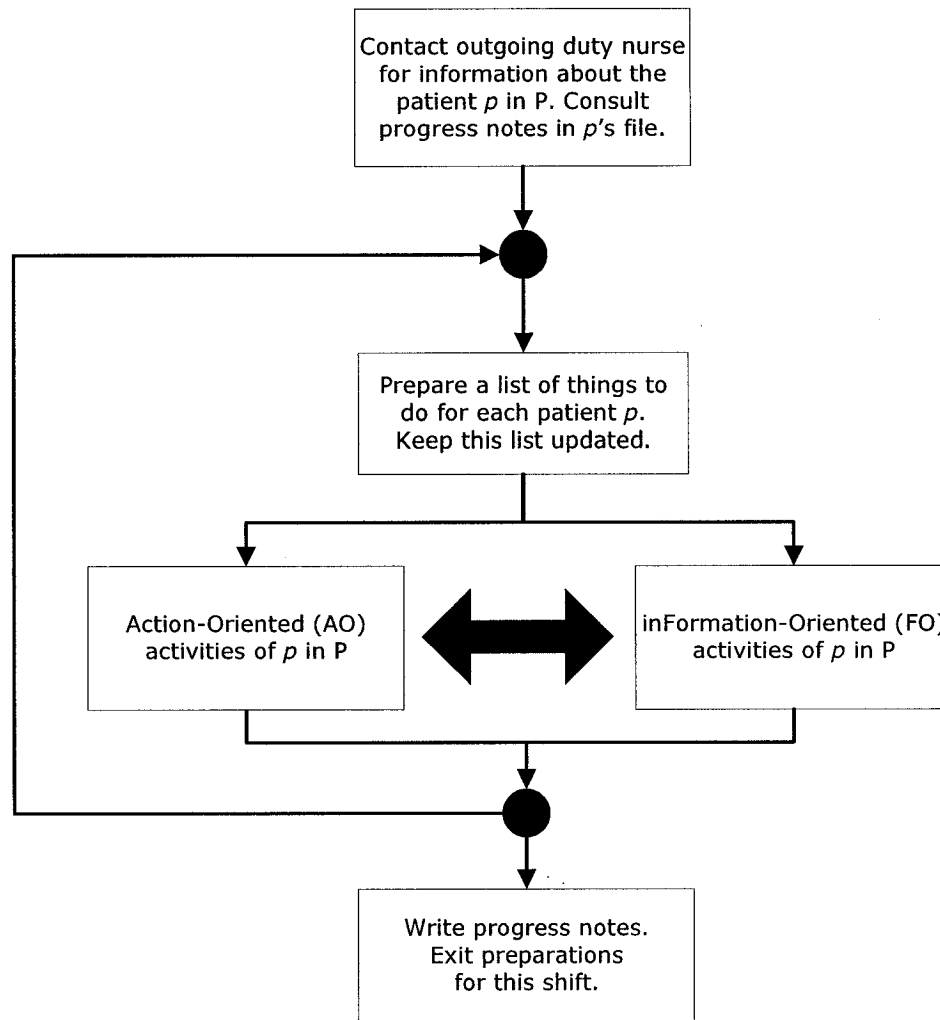


Figure 3.1 – Nursing process (abstract view)

This behavior adds considerable constraints in designing an IS for the use of transplant nurses since they are extremely stressed while doing their work. While proper help from a computer system would be beneficial in more than one way, an improperly designed system would only add to their stress. In addition to details regarding the ward's current IS, our other subsequent observation was a general fear among certain nurses of changes that might accompany the introduction of IT. Consequently, during our ethnographic study, we noted specific comments and decided to use them as input to our design of the NUI software system.

3.3 An Ethnographic Study of the Organ Transplant Ward

A comprehensive understanding of an organizational unit stems from the understanding of all its underlying activities [96]. Consequently, in order to develop a useful software application to assist the nurses in their work, we needed to first understand the activities that take place in the organ transplant ward of this hospital. In the healthcare industry, this understanding of complex hospital activities involves process modeling [42, 56]. However, prior to a discussion involving process support, we must start by understanding the particular nuances of how these processes together compose the current workflow of this organ transplant ward. This would enable us to better understand the problem domain from a global perspective and consider all implications of integrating computer-support into, in our case, the nursing care process. Furthermore, we felt that we had to ensure that drastic changes to the current practice would be minimized. When needed, such changes have to be first well examined by the stakeholders; failure to do so would otherwise most likely vest support into the production of an unacceptable system. However, in attempting to gain this insight – we faced a major challenge.

The challenge we faced was that no recorded workflow model of activities at the organ transplant ward was available to us. Instead, we found that several distributed process-flows exist which are well understood by different actors and followed systematically by related groups of actors. Paper-based forms, formal form-flow procedures, and informal and formal communication (among the actors) of the distributed processes help to piece these multiple processes together to offers today's global coordinated service. Consequently, we needed to piece together the “big picture” for our understanding. Our

challenge was then to understand and model all the related distributed processes and examine the nursing process in this light. In order to meet this challenge, we conducted an ethnographic study and several interviews of members at this organ transplant ward.

An ethnographic study can broadly be described as the qualitative description of human social phenomena based on fieldwork [97]. Today it is being used increasingly as a method to submerge a researcher in another social environment to discover specific details about how work is done. It involves the immersion in a working context (society) to make detailed observations. These observations then reveal information about the structure, organization, and practices of these societies. The rationale for ethnography is that actual work processes tend to differ from documented work processes. The ethnography process does not make any pre-suppositions about the society but rather gets insight into practices, cooperation, and processes. Although ethnography is a process derived from anthropology, its potential value in deriving computer system requirements is becoming increasingly apparent [98–100]. This activity ensures that system requirements are not defined according to documented procedures and standards but rather aligned to actual working practices. Consequently, ethnographic studies are believed to be particularly useful when attempting to understand and model socio-technical systems like healthcare [101–104].

In its entirety, our ethnographic study of the organ transplant ward lasted six-weeks. It was performed with the permission of the head nurse and willing cooperation of several nurse volunteers. We started by attempting to identify the core activities that constitute

nursing work. In order to do this, we had a member of our research team “shadow” a nurse volunteer while they performed their nursing activities². We performed this analysis of nursing work activities using a sample of three nurses over a two-week period. During this time, we were able to observe how the distributed work activity of healthcare involves multiple actors. Working together, these actors ensure the type and quality of care-giving activities. However, with a large number of different actors involved in this care process, it became increasingly difficult for us to model the diversity of the individual actors along with dependency and communication needs at this level.

Upon completion of our initial ethnographic study of nursing activities, we had obtained significant insight into the role of nurses in the care path of patients. This insight allowed us to better appreciate the complexity involved in the care and treatment of organ transplant patients. We were also able to identify other actors that take part in this care process as doctors, surgeons, nurses, and other support staff, collectively referred to as Healthcare Providers (HCP). Having identified and become familiar with these other actors involved in this coordinated care process through the study of nursing activities, we could easily perform subsequent ethnographic studies on other groups of actors to slowly piece together their roles in the form of distributed and coordinated processes.

The care-giving process followed by HCP embeds both structured and unstructured processes to meet the timely needs of patients. In this context, we view the term *process* to include both actions by different actors and communications among them. Several such processes are distributed and coordinated in care-giving. The situations faced in this

² Specific details regarding our ethnographic study can be found in Appendix A

process are then extremely complex, formal as well as informal, dynamic, and widely varied. Using the compiled information, we pieced together a global process model, or workflow, of how these distributed process-flows are aligned to offer a global coordinated service. This exercise allowed us to identify eight well-defined process-flows involved in the day-to-day operations of an organ transplant ward. These processes include:

1. The Admission Process
2. The Work-Allocation (WA) Process
3. The Unit-Coordinator (UC) Process
4. The Nursing Process
5. The Computerized Physician Order Entry Process (CPOE) Process
6. The Pharmacy Process
7. The Discharge Process
8. External Processes (e.g. Dietician Process, Radiology Process, etc.)

Our organization of these eight processes to create the global process model of activities at the organ transplant ward of this hospital is shown in Figure 3.2.

3.4 Process Modeling

After having modeled the workflow of the organ transplant ward in the form of a set of eight interacting processes, we in turn modeled each of these processes in more detail to capture the significant activities of each process. Now, in this context, a *process* consists of several activities that have relationships among them. Therefore, within each process,

different actors can perform activities in sequence or in parallel with constraints understood in an explicit or implicit fashion.

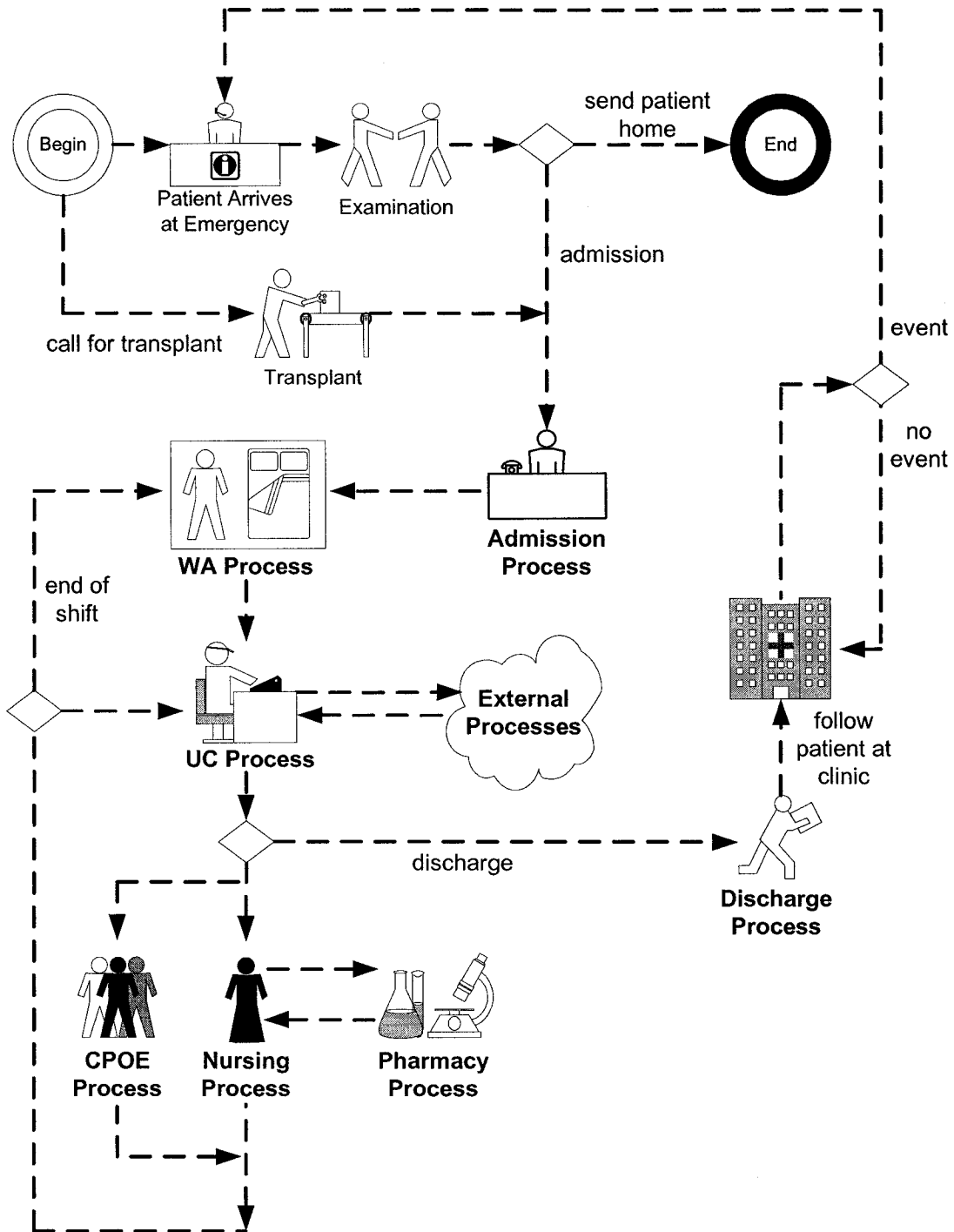


Figure 3.2 – Global process model (workflow)

In the organ transplant ward, we observed that care-giving is highlighted by both data accumulation and the coordination of ward activities. For the purposes of modeling, we define two types of activities in these interacting processes which we denote as *Action-Oriented (AO)* and *Information-Oriented (FO)*. The former are physical actions performed by the HCP; while the latter includes, among others: data entry, information access, information communication, and message communication. We believe that the extraction and categorization of ward activities into AO and FO is a good way to systematically understand the peculiarities of how the current paper-based system helps in the coordination of ward activities.

In Figure 3.3, we define p and p' as the interaction between FO and AO activities before and after “changes” to the current information system have been made. We can then characterize this interaction on three dimensions: (1) constraints (hard vs. soft), (2) performance (time spent) and (3) adaptation (learning, benefits to others, self). Of these three dimensions, we look to increase the performance of a new system while attempting not to disrupt the current level of constraints and adaptability.

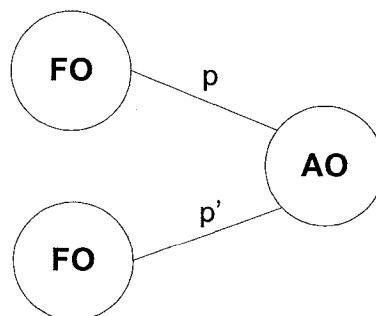


Figure 3.3 – AO vs. FO activities

If we look at the delivery of healthcare, medical personnel would much rather spend their time treating and helping patients rather than spending time on FO activities. Obviously, this increased concentration on the treatment process is also highly desirable from the perspective of patients. With this in mind, a reduction in the time spent on FO activities would allow more time being available for AO activities. It is important to note, however, that the ratio of work done in FO activities is dependent on the role of the healthcare actor. For instance, let us define R as

$$R = \frac{time_spent(FO)}{time_spent(AO + FO)} * 100\%$$

Note that R defines the percentage of the amount of time a healthcare actor spends on FO activities. While coordinators and researchers would have R closer to 100%, nurses and Patient Care Associates (PCAs) should ideally and desirably have R close to 0%. Physicians, on the other hand, would be somewhere in between these two extremes.

Thus, in order to ensure that our process models were complete and accurate portrayals of the workflow, we imposed the following requirements:

1. The process models must indicate the usage of all paper-based records.
2. The process models must indicate collaboration with other healthcare actors.
3. The process models must portray both synchronous and asynchronous events as well as the concurrency of activities.
4. The process models must indicate whether activities are AO or FO oriented.
5. The process models must remain easily updatable to adapt to future ward process changes.

Using the information we compiled from our ethnographic study, we began dividing each interacting process into a set of atomic activities. Following this exercise, we decided that we required a model-based specification to represent these interacting processes. With the desire for diagrammatic depiction, we decided to make use of the standardized graphical notation set provided by the Unified Modeling Language (UML). However, although we initially started with the framework from UML activity and state diagrams, the variation of clinical processes required that we deviate from the standardized UML notation. As a result, for the sake of both precision and simplicity, in the end, we provide our own notation for diagrammatic depiction of the processes. However, we note that the majority of symbols employed in our graphical notation are derived directly from UML. These symbols are shown in Figure 3.4.

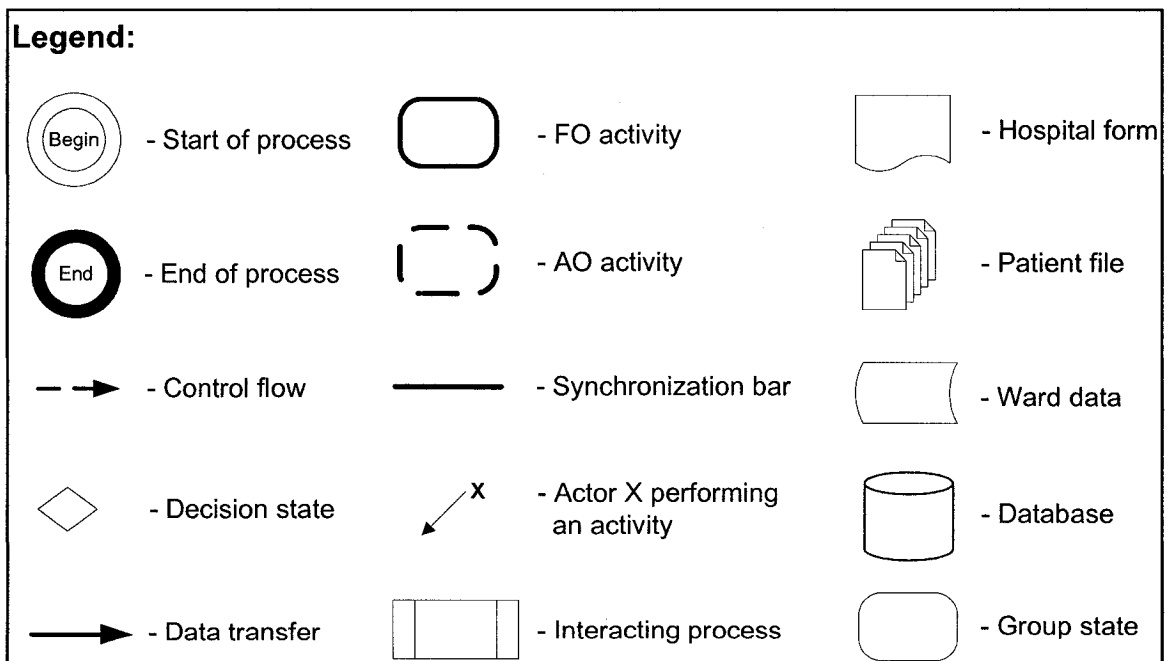


Figure 3.4 – Symbols for the process diagrams

After having created the first versions of our models, we organized review sessions with sets of related actors in order to review and validate our understanding. Based on the feedback, we re-worked and refined our models and present them below.

3.4.1 The Admission Process

The *Admission Process* is a well-defined ward process that involves the collective cooperation of the unit coordinator, an attending nurse and the admitting physician. The activities in this process are entirely FO-based and involve assimilating and documenting patient data for subsequent nurse care throughout the patient's stay at the organ transplant ward. In addition, this process involves physicians ordering medications and any other relevant tests that might be necessary based on the patient's specific transplant situation. Unlike many other ward processes, this process is not continuously ongoing and thus occurs with much less frequency. Figure 3.5 depicts the coordinated activities of the Admission Process.

3.4.2 The Work-Allocation (WA) Process

The *WA Process*, like the Admission Process, is a well-defined ward process that involves the unit coordinator, the head nurse and the load balancer³. This process has two major objectives. Firstly, it allocates patients to an available room and bed on the ward. This could be necessitated either through a new admission or by potential infectious outbreak that requires a patient to be quarantined in the ward. Secondly, this process determines nursing work shifts and the assignment of patients to nurses-on-duty. The

³ The load balancer is responsible for assigning patients to nurses-on-duty

frequency of execution of this process varies and can occur concurrently with other ward processes. Overall, this process is concerned with organizational and logistical details as opposed to functional particulars of patient care. The activities involved in the WA Process are shown in Figure 3.6.

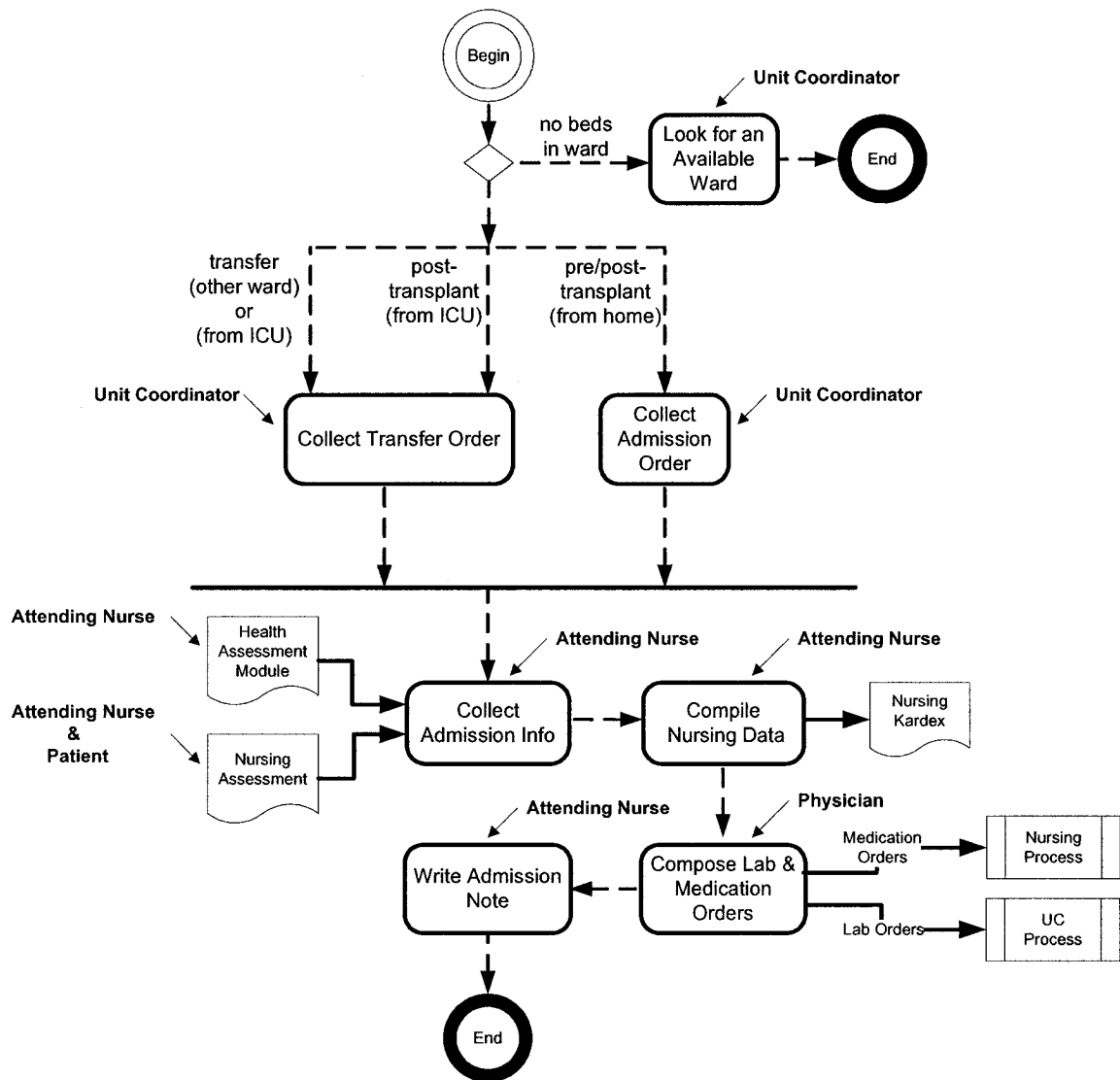


Figure 3.5 – The admission process

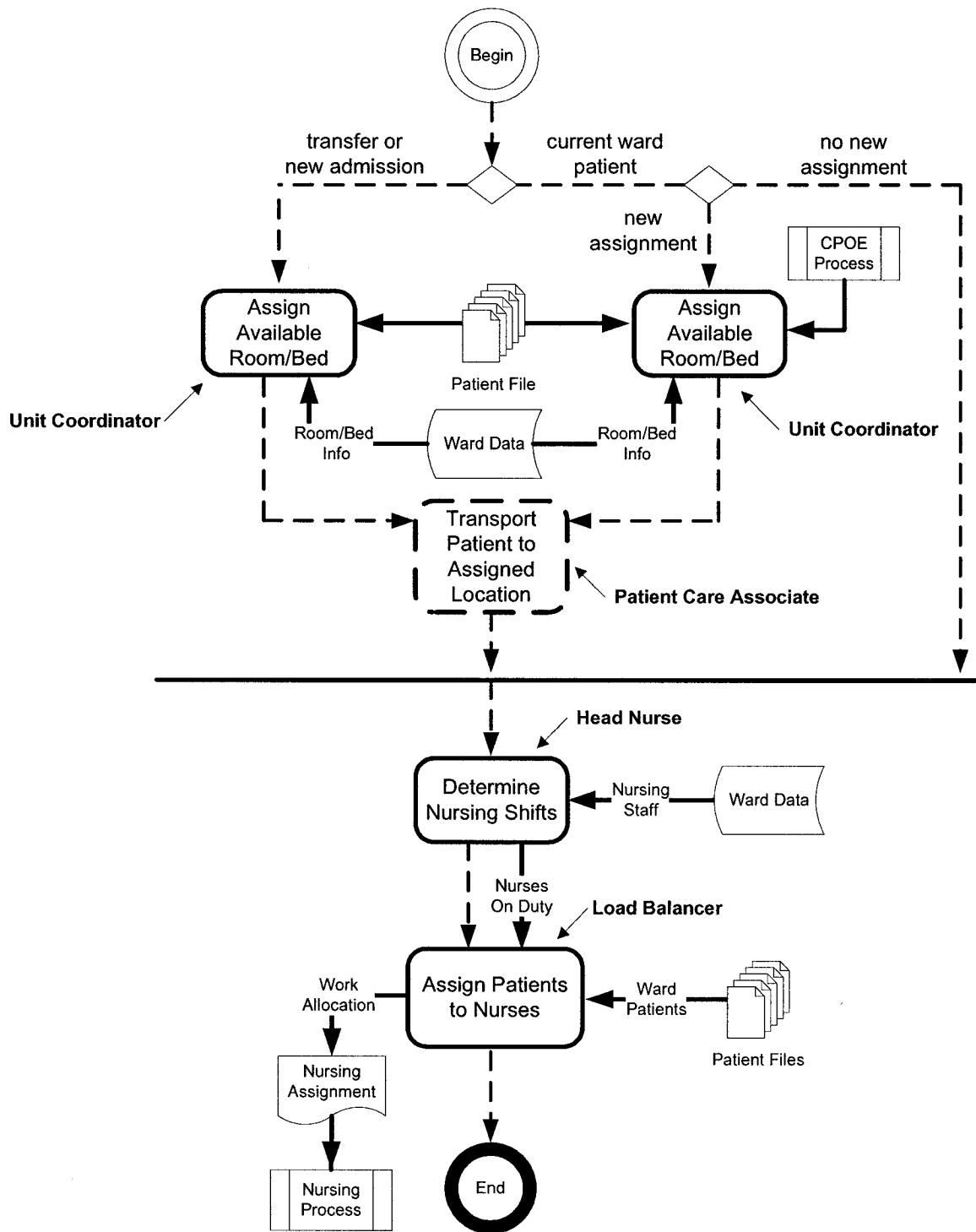


Figure 3.6 – The WA process

3.4.3 The Unit-Coordinator (UC) Process

The *UC Process* depicts the stream of activities performed by the unit coordinator at the organ transplant ward. In fact, during the day, every ward has a unit coordinator on shift who works in the nursing station to oversee ward activities. They serve as the main liaison that coordinate and organize activities with different units in the hospital as well as with the outside world. Their primary responsibility is the constant collection and dissemination of information for the entire ward. Their actions and coordination ensures that the ward functions as a unit. Among other things, they: (1) access remote information needed by physicians, (2) assist in the admission and discharge process of the ward, and (3) relay lab orders to appropriate medical departments. In addition to their important affiliation with external entities, they also work in close proximity with nurses and doctors to constantly remain aware of the ongoing location of ward patients at all times.

With such a large responsibility, unit coordinators are constantly overworked. In addition to this already complex structure of tasks, they must also field phone calls and relay messages to actors in the ward. With such a dynamic and highly involved work activity, the framework of their activities is very much ad hoc. This is perhaps inevitable since unit coordinators are constantly disrupted by new tasks and aperiodic activities. In fact, as we were able to learn from the nurses through our ethnographic study, unit coordinators assist and play simultaneous roles such that they are the lifeline of the ward. As such, although they perform exclusively FO-activities, their absence would ultimately paralyze the ward care process. This intangible aspect of their role in the care process is in fact impossible to model to all its level of details. However, in Figure 3.7, we abstract the

behaviour of unit coordinators in the UC Process by designing a core sub-process that is continually disrupted by external events. These events are handled according to a dynamic priority scheme.

3.4.4 The Nursing Process

The *Nursing Process* is an “around-the-clock” ward process that identifies activities performed by nurses-on-duty. Despite the persistence of the process, however, the Nursing Process periodically terminates for short intervals and resumes as per the organization of new nursing shifts. This process is extremely involved and is characterized by two major activities: physically nursing patients and information recording activities. Consequently, this process exhibits constant shifts in the nature of work among AO to FO activities. At times, due to the unpredictable nature of medical work, this can result in severe cases of information overload that provides significant stress on nurses. Currently, a paper-based system is in place that exists to support FO activities.

At a very rudimentary level, we can analyze the Nursing Process as a three-step process. The first step is well defined and involves the accumulation of relevant patient information regarding all patients that a nurse is assigned to on their upcoming shift. This step helps nurses to uncover specific issues of care and therefore identify the nursing needs for each of their patients. Consequently, nurses are able to properly plan their nursing interventions. Apart from an abbreviated oral conversation with the outgoing duty nurse, this step of data assimilation relies exclusively via paper-based hospital forms.

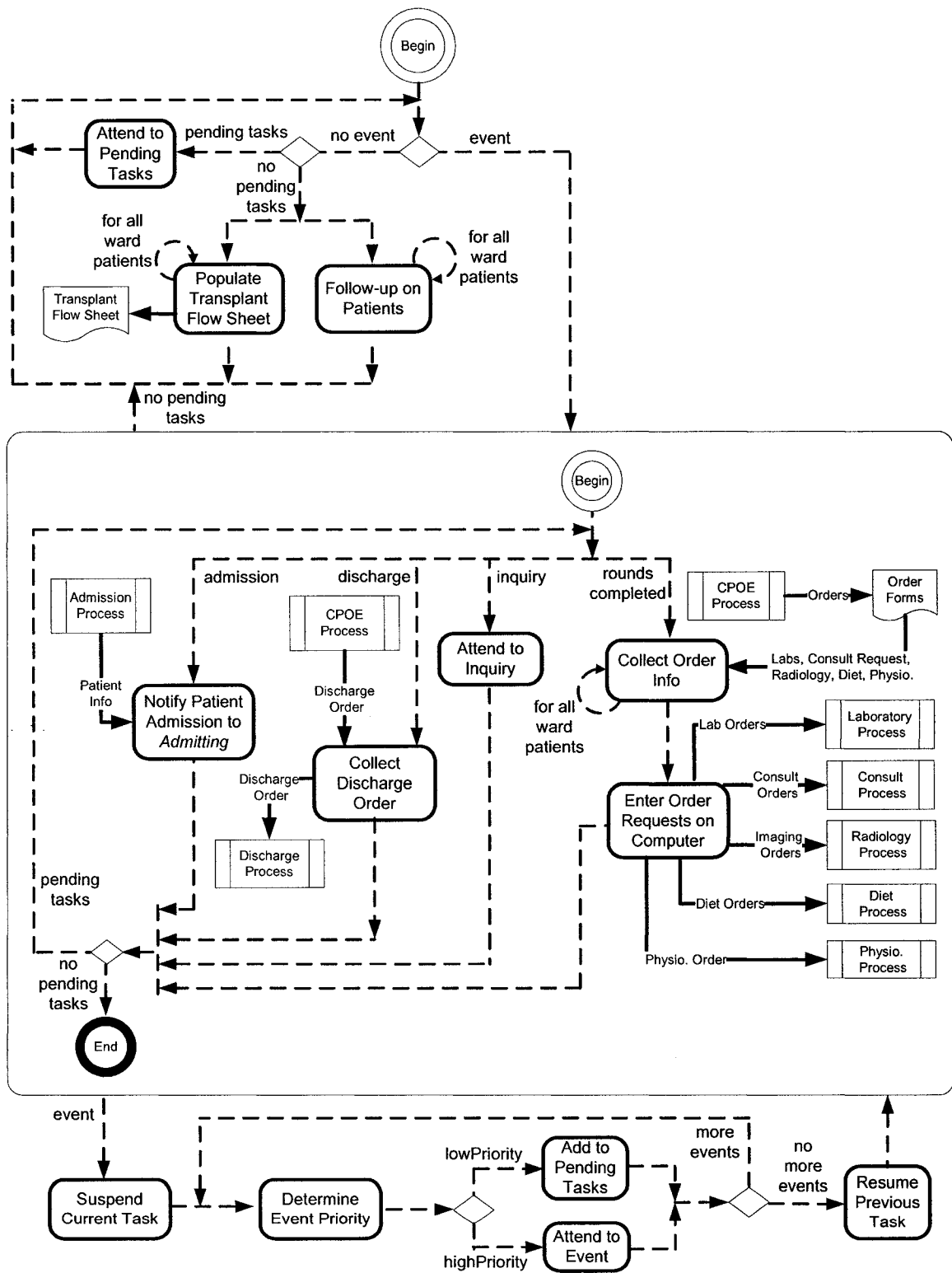


Figure 3.7 – The UC process

The second step of the Nursing Process, which identifies the core work of nurses, is not well-defined. In this step, nurses are constantly changing their activities as the situation demands between the physical care of their assigned patients and paper-based documentation. In this sense, their work is not completely structured and constantly varies. In terms of their work, AO activities correspond to physical actions performed by nurses and FO activities include, among others, data entry, information access, information communication and message communication. During this second step, our most important observation was discovering that the time spent for FO activities is not trivial. In addition, since the nursing documentation activity serves a legal requirement and supports patient-centered nursing care, it cannot be avoided. Taken as a whole, the key characteristic of this second step of the Nursing Process is that it is highly unpredictable and involves significant changes in dynamic priority settings that results in demanding work and an information overload for nurses. As such, due to the nature of this work, we observed that the many widely varying constraints and characteristics of individual nurses make them cope differently with this demand.

The third and final step of the Nursing Process is structured but its time of completion varies greatly on individual nurses as well as circumstances. It involves nurses completing their work shift and carrying out any residual nursing documentation that they were unable to complete during their shift. This is followed by debriefing the incoming duty nurses about their upcoming assigned patients. The Nursing Process and all its associated activities are shown in Figure 3.8.

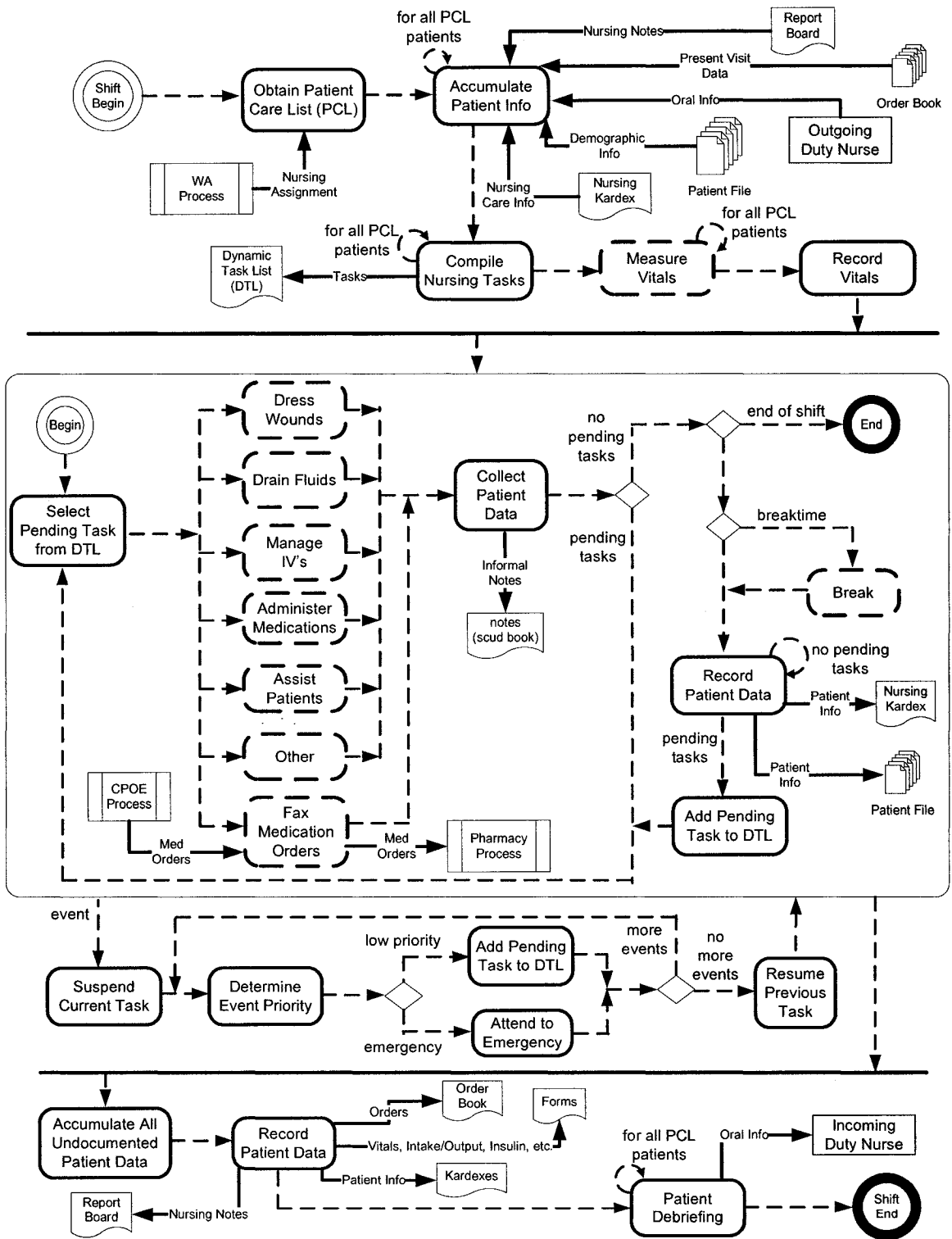


Figure 3.8 – The nursing process

3.4.5 The Computerized Physician Order Entry (CPOE) Process

In the transplant ward, the *CPOE Process* highlights the core of the care process. This process involves direct interaction between physicians and patients to assess the patients' status and changing needs. In order to do so, the CPOE Process systematically generates a set of actions and orders that are collectively met by other processes in the ward. Consequently, this process structures the sequence of work for all other processes in the ward. However, in this ward, the CPOE Process is not currently automated.

The CPOE Process, often synonymously referred to as the rounding process, is divided into three steps. The first step is the data collection stage in which pertinent data for all patients in the ward is collected. This is a lengthy and tedious process since this data is often geographically dispersed in the ward. This data gathering activity is usually performed systematically by medical students. The second step is the actual rounding process in which the medical team visits each and every patient in the ward to evaluate their health. The average attention given to every patient is approximately three minutes. During this time, the physicians use the data collected and digested in the previous step and interact with patients to determine if any changes are needed in the treatment and care of the patient. Upon agreement by the medical team of the changes to patient care (medication changes, lab orders, etc.), these changes are recorded. After having attended to all patients, the third step involves authorizing all orders and submitting them to the unit coordinator and to the nurses. The CPOE Process occurs twice daily and its average completion time is 90 minutes. The activities involved in the CPOE Process are shown below in Figure 3.9.

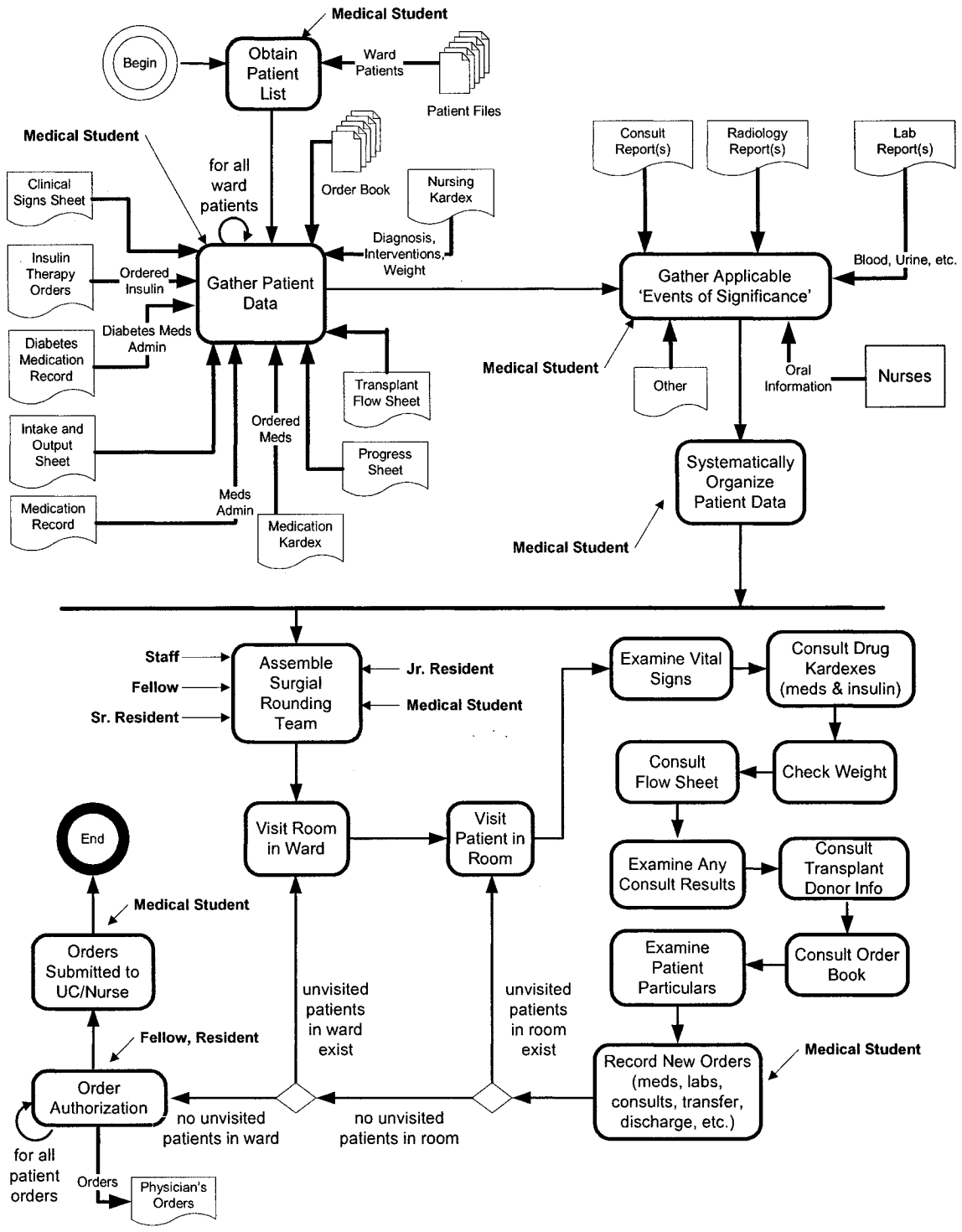


Figure 3.9 – The CPOE process

3.4.6 The Pharmacy Process

The *Pharmacy Process* is concerned with activities required to translate a physician's medication order into administrable medications to be dispensed by nurses. This process involves the interaction between a pharmacist and the attending nurse. Although this process is external to the transplant ward, we chose to model it independently since nurses are the only actors who interact with this process from the organ transplant ward. Despite their affiliation with all other external ward processes, unit coordinators are not involved with the Pharmacy Process. Likewise, physicians also do not play a significant role in the Pharmacy Process. They assume, for all intents and purposes, that the medication will be ordered, delivered, and administered as prescribed.

The Pharmacy Process can be divided into three steps. The first step involves nurses collecting authorized medication orders and subsequently faxing them to the pharmacy. The second step is the verification and validation of these medications for each case by the pharmacist. This extensive verification and validation process involves: (1) ensuring that the medication does not react negatively with the patient's currently prescribed medications and (2) the physician has prescribed a dosage that correlates with various patient-particular details. Finally, the last step of the Pharmacy Process is the actual preparation and delivery of the medications from the pharmacy to the target destination. Notice that, while the first two steps of the Pharmacy Process involve primarily FO activities, the final step involves exclusively AO activities. The activities that constitute the Pharmacy Process are shown below in Figure 3.10.

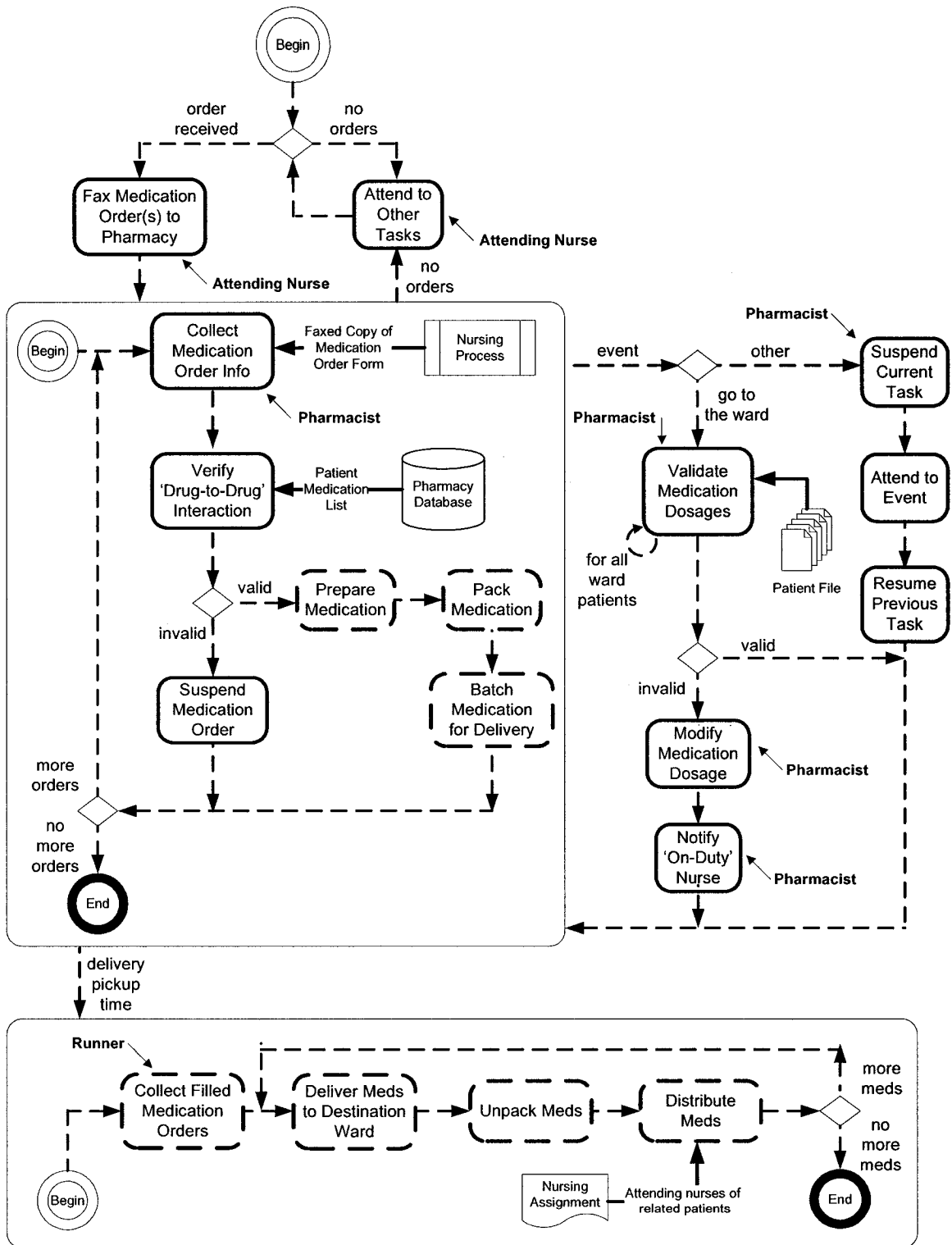


Figure 3.10 – The pharmacy process

3.4.7 The Discharge Process

The *Discharge Process* contains the set of activities that unfold following a physician's completion of a patient discharge order. Since the majority of patients leaving the transplant ward have just received a transplanted organ, this is an involved process that entails the simultaneous cooperation of a physician, the unit coordinator and an attending nurse.

The Discharge Process can be divided into three steps. The first step initiates the process and involves the unit coordinator's collection of an authorized discharge order. The second step involves preparations for the patient to leave the hospital. This includes, among other things, a physician ordering the required "take-home" medications, nurses educating patients on their self-care and the unit coordinator helping to organize a follow-up appointment for the patient at home, at the local CLSC, or at the transplant outpatient clinic. The third and final step of the process includes the removal of the patient from the active hospital database system and the transfer of their information to the medical records department. Similar to the Admission Process, the Discharge Process occurs with much less frequency than other ward processes. The activities that constitute the Discharge Process are shown below in Figure 3.11.

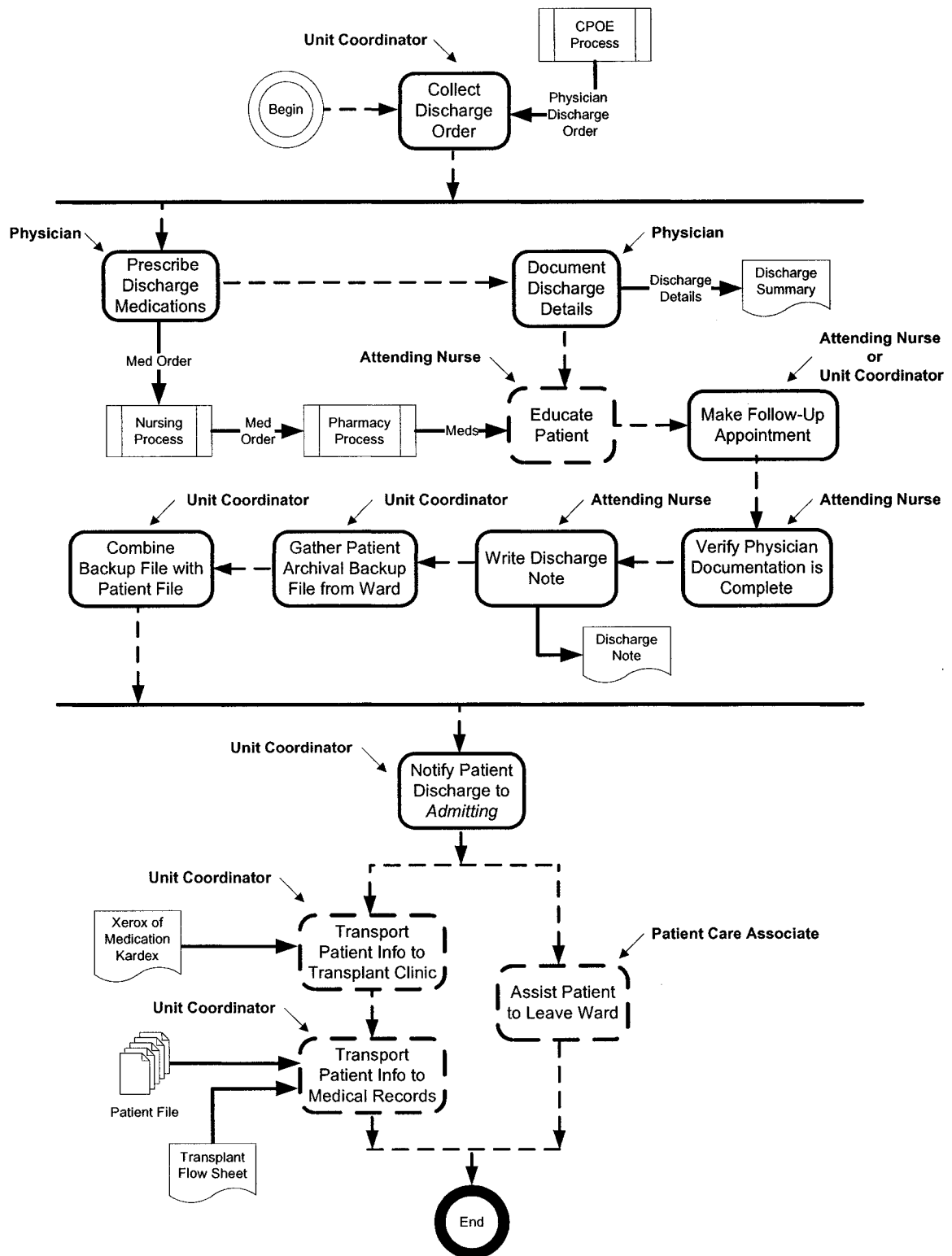


Figure 3.11 – The discharge process

3.4.8 External Processes

For the purpose of completeness, we modeled all processes that occur outside the organ transplant ward as external processes. Apart from the Pharmacy Process, which we chose to model separately due to its close affiliation with the Nursing Process, all external processes are initiated by the unit coordinator through the UC Process. These external processes are mostly in the form of consults that are relayed to the appropriate hospital department by the unit coordinator after having been ordered by a physician. Although each consult is handled differently by the many different hospital disciplines, we abstract them together for simplicity. This is shown below in Figure 3.12.

3.5 Summary

From our study of the workflow at this organ transplant ward, we identified eight interacting processes that are involved in the day-to-day care of patients. By modeling each of these processes based on observations from our ethnographic studies, we were able to gain significantly new insight into the work system of this clinical communication environment. Among other things, we learned that each process is inherently different and involves people engaging in different activities at different times with machines, tools, documents, and many other artifacts. We also learned that clinical workflows are indeed well suited to be modeled as processes since it is the case, as we observed, that there is considerable variation in the way in which HCP do their work. As a result of many limitations, highlighted by our own time constraints and the availability of healthcare volunteers, we were unable to develop computer support for all interacting

processes that take place in the organ transplant ward. This constraint ultimately necessitated that we select one particular process that we could use as an understudy that would be complex enough for us to justify our research.

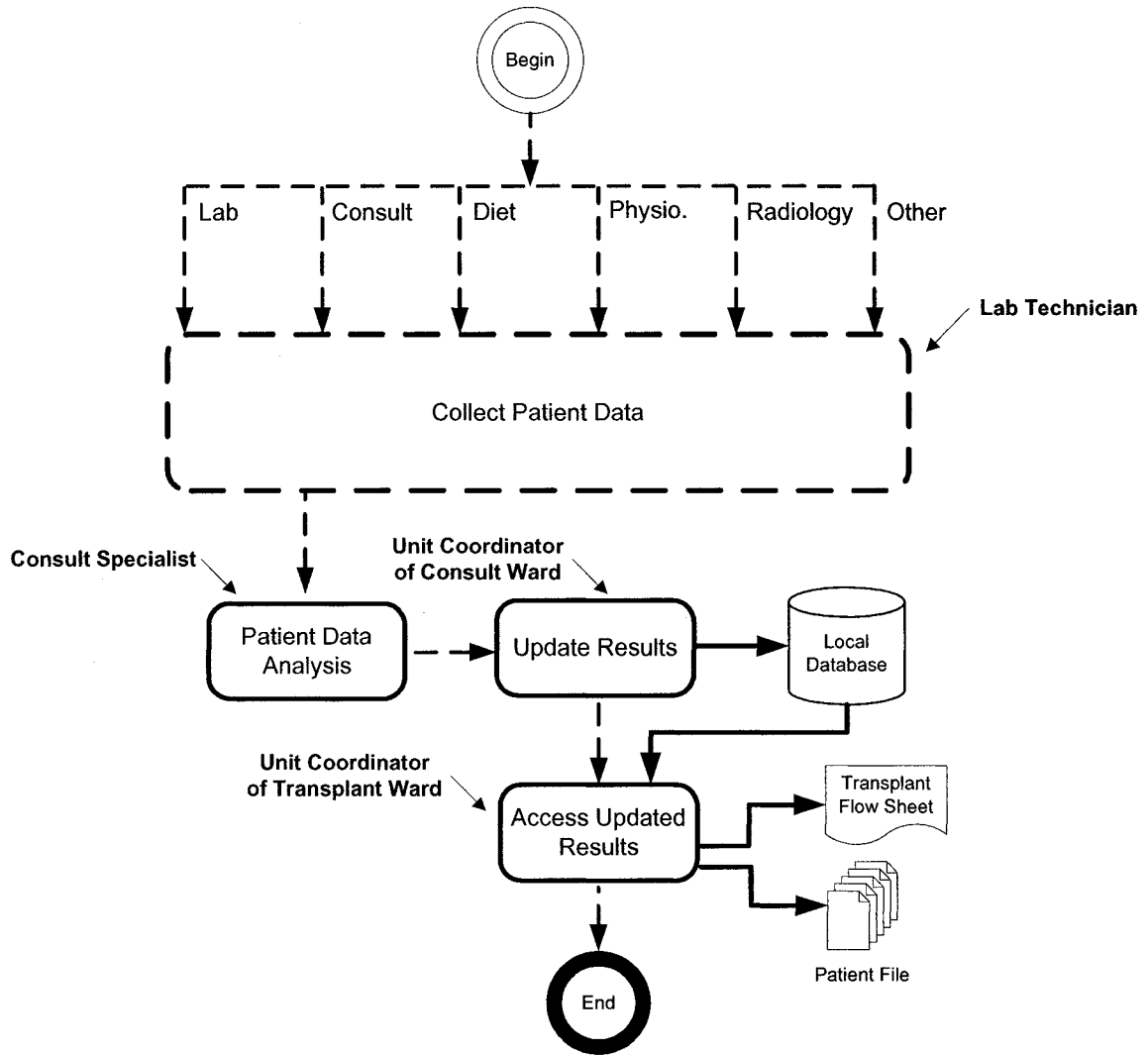


Figure 3.12 – External processes

In the end, we decided to select the Nursing Process because it is one of the more complex processes within CIS and offers a good balance between the interaction of human and non-human elements by way of structured as well as unstructured communication. Furthermore, it has been reported that as nurses constitute the largest

population of the healthcare workforce, their acceptance of IT is a key determinant in successful CIS implementation [95]. Finally, the cost-benefits expected from the successful deployment of computer-support in nursing are expected to be one of the highest among the different components of CIS.

With this in mind, we proceeded to design a software system that supports the Nursing Process. Using a view of the interacting processes, and developing the Nursing Process using process discovery through iterative requirements elicitation, we believed we could design a system that could be well integrated with other components of CIS as they develop. We reasoned that addressing the problem in such a manner provides an effective solution since it offers a mechanism to ensure the acceptance among all project stakeholders. In addition, we expected that the design and the demonstration of the Nursing Process, through our NUI software, would be an effective way of convincing stakeholders to migrate towards computer applications, particularly when viewed from the nurses' perspective.

We believed that our approach would be effective since its foundation remains based on the understanding of medical work practices of healthcare professionals that have evolved over many years. It is unwise to expect healthcare practitioners to depart from their familiar work practices in the care-giving process for the sake of facilitating the introduction of IT. By systematically understanding the needs of all involved actors in a global sense and by piecing together different healthcare processes, we understood the needs of users in two levels of granularity: coarse-grain (view of processes) and fine-

grain (view of activities). In addition, we believed that this approach of introducing IT would help to ensure that the changes from the current system to a computer-supported one would cause only minimal and necessary deviations. As such, we reasoned that it would have a better chance of success.

Following our ethnographic study and modeling exercise, we believed a rigidly structured system designed with no specific concern for the work practices of nurses in the organ transplant ward would be unable to cope with all the needs of a transplant center. We have witnessed this to be true in our field trip to a large transplant center⁴ where they are facing a system that imposes significant rigidity on both nurses and physicians. As a result, deviations in the course of pre-planned treatments require specialized exception handling that proves extremely cumbersome and time-consuming. It is from this experience that we have learned firsthand that implementing a system that cannot meet the daily needs of medical personnel and provide a suitable level of flexibility (in the event of variations in patient care) will not be accepted. This flexibility is achievable through understanding of the considerable complexity of the clinical working scenario.

⁴ This transplant center is also a teaching hospital and treats a larger number of transplant patients compared to the transplant center where we performed our ethnographic study.

Chapter 4

A Design Methodology for NUI

In the previous chapter, we developed a workflow model of interacting processes in a typical organ transplant ward at a large metropolitan hospital. Through these modeling efforts, we observed how healthcare exists as a collective, cooperative, and distributed enterprise that involves several processes performing multiple coordinated activities. Furthermore, these process models clearly indicated that in addition to data accumulation, the current paper-based recording system of hospitals is used to address the need for coordination among caregivers.

We have selected the Nursing Process for our deeper study and design and in this chapter we present and discuss the software design methodology we used to develop the *Nurse User Interface* (NUI) software system for nurses. We were first faced with the challenge of choosing an appropriate software engineering process that would be suitable to meet our two goals of usability and acceptability. The details of our design process are discussed herein.

4.1 Overview

The design of the NUI, which involved an extensive iterative process, was spread over 15 months. It involved the cooperative efforts and participation of volunteers (primarily

nurse volunteers) from the organ transplant ward. As mentioned in Chapter 3, our design strategy started with an approach to gain insight into the global view of ward activities. This approach eventually served to focus us on the Nursing Process in particular. The design process of the NUI to support the Nursing Process required three development stages. The design process viewed as a black box has three different types of input as seen below in Figure 4.1.

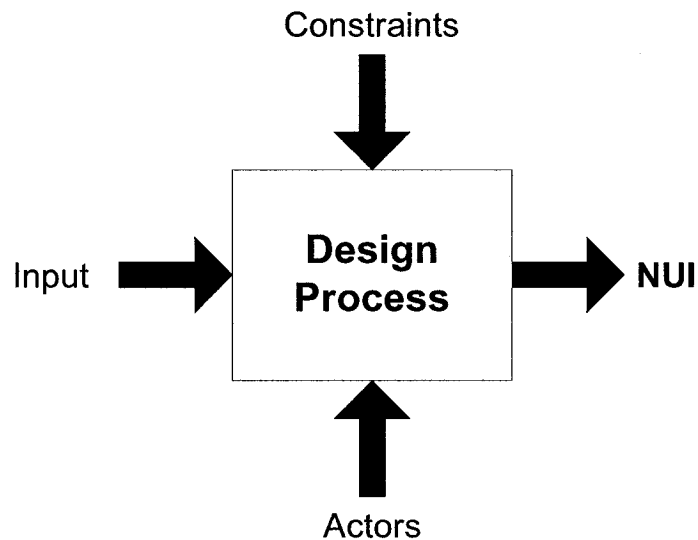


Figure 4.1 – NUI design process — overview

4.2 Design Goals

The two major design goals of usability and acceptability were set based on our overall study.

Usability

Usability is a measure of the amount of effort a user must expend in order to interact with a system [105]. In the case of developing an NUI for nurses, usability relates to the

relative ease of using the system to perform prescribed medical documentation tasks. Since the nursing workforce is constantly overworked and highly stressed in their patient care, an IS intended for their use needs to ensure it does not add additional burden for them. As such, it is our desire that the NUI should be simple to learn for most nurses and as easy to use as their current paper-based documentation system used in the organ transplant ward.

Acceptability

While usability is a function of the ease of use of a system, acceptability measures whether or not the system will be used. In terms of the NUI, acceptability addresses the question of whether a usable system can be integrated into the overall hospital system. Since acceptability is a broad topic for our present needs, we define acceptance as meeting the needs of both categories of end-users; nurses as well as all other hospital stakeholders (i.e. PCAs and the head nurse of the organ transplant ward). A suitable NUI then needs to support a diverse nurse workforce in performing their healthcare activities as well as hospital stakeholders who wish for a system that is useful, reliable, cost-effective and compatible with other systems. It is our desire to ensure that the design process takes these multiple viewpoints into account to ensure that the NUI provides a positive appeal to all stakeholders.

4.3 Design Strategy

After having identified our key design goals as usability and acceptability, we faced the challenge of selecting a suitable software engineering process that would be appropriate

for the NUI. In the end, we decided to follow a design approach that combines two approaches – UCD [81] and XP [72].

In a recent publication dated May 2005 [106], UCD and XP are combined to form a new system development design paradigm. Since our research efforts have been in progress since 2003, our work has been independent of their study. With this in mind, a brief overview of their work reveals that they have attempted to determine particular UCD tools that can best harmonize with the iterative development of XP. Through a detailed study of the strengths and weaknesses of each approach, their method proposes adding an initial phase outside the scope of XP iterations. The author argues that although this seems to violate the basic principles of XP, combined in the right way, benefits can be achieved. This initial phase, which the authors coin as the *project inception phase*, uses a variety of UCD tools and techniques in order to help build a persona. This persona is used in turn to help determine how different groups of people will interact with the system and help prioritize between interaction scenarios. With personas helping to minimize the risk, this new method remains agile; but to a different degree. However, awaiting actual development, it remains to be seen the merit that this approach will bring to the design community.

From previous research [31, 34], we discovered that traditional software engineering design techniques are inadequate in handling the development of IS in healthcare. For the most part, as we discussed in Chapter 2, these techniques are unable to handle incomplete and changing requirements and have led to systems that have been unable to meet the

needs of the medical community. At the same time, we were also aware of the two extremes: (1) the “one-size-fits-all” syndrome is not applicable due to wide variations in the healthcare practice and their differing requirements; and (2) at the other extreme, software developers know that custom-made software products are expensive both for development and for maintenance.

Consequently, we felt that the best compromise could be achieved by following the set of principles that embody a UCD approach. This approach of considering the user, their work, and their environment of work to determine how IS can be best deployed to support them becomes a logical choice. Participatory Design (PD) [85] is one of many specialized methods under the broad category of UCD. This approach to design empowers end-users by allowing them to directly participate in the design to help ensure that the end product will meet usability goals. In addition to UCD principles, we also involved some of the ideals preached by agile software development through XP in order to offset UCD’s lack of flexibility for constantly evolving requirements.

The XP software development process [72] is an agile software development process characterized by customer involvement and teamwork that promotes the early and continuous delivery of software in order to use multiple iterations and feedback as primary control mechanisms. With our initial understanding of constraints faced by nurses being incomplete when we started our design, XP was well suited as an iterative design process to allow for changes in requirements to occur throughout the design. These requirement changes would then hopefully involve minor changes due to the short

duration of design-test-redesign cycles. It is important to note that although we did not employ the XP ideology in its entirety, we applied the majority of its main set of beliefs.

Our resulting methodology could then:

1. Focus on end-users from the point of view of their work and their environment.
2. Provide a rapid iterative design that involves users directly in the design process.
3. Provide the flexibility to welcome changing requirements.
4. Ensure minimal risk for all involved stakeholders by assessing the needs of other stakeholders in every design iteration.

Although many causes of failure for CIS have been well identified, one of the most important shortcomings has been the lack of a well-suited design process that understands the practice rather than attempting to drastically revolutionize medical protocols [26]. With this in mind, our belief at the beginning of this applied research project was that the application of a design process that preaches a combination of UCD and agile software development can ultimately advocate the development of a NUI that focuses on our two design goals.

4.4 Software Design Pattern

In designing the NUI, we applied the classic design pattern of Model-View-Controller (MVC). This pattern is well suited to this project since it places emphasis on separating the application object (model) from the way it is represented to the user (view), from the way in which the user controls it (controller). In other words, the model subsystem is

responsible for maintaining domain knowledge, the view subsystem is responsible for displaying it to the user, and the controller subsystem is responsible for managing the sequence of interactions with the user. Since the NUI is an interactive enterprise application that has to ensure that vast amounts of medical information is presented in a comprehensible and digestible format for nurses, the proven MVC design pattern becomes a logical choice. By providing significant flexibility for multiple views using the same enterprise model, this pattern provides support for multiple clients by offering a layered design that is easily distributable and allows for significant ease of growth. Figure 4.2 illustrates the MVC design pattern applied to the NUI.

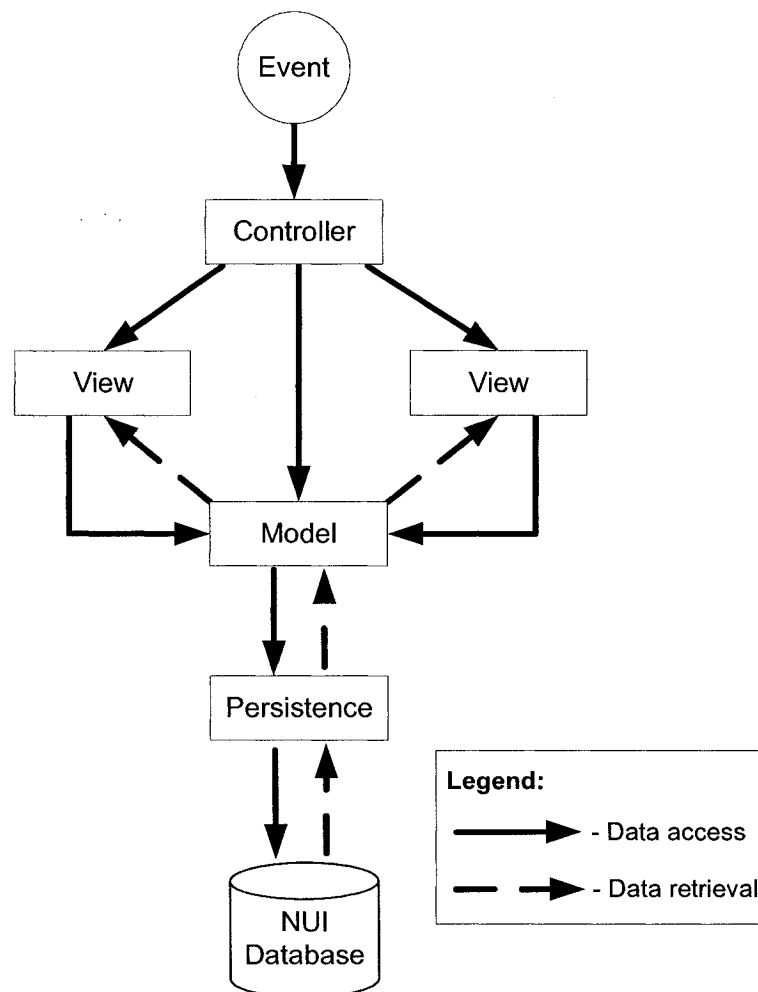


Figure 4.2 – MVC design pattern applied to the NUI

4.5 NUI Design Process – Stage 1

The first stage of the design process was lengthy and took eight months to fully complete. The extended timeframe was the result of many initial decisions that needed to be addressed since we wished to produce a working prototype at the end of the first design stage. All decisions taken with respect to the NUI in this first design stage were based on UCD principles (see Section 2.5). Figure 4.3 illustrates the first stage of the NUI design process.

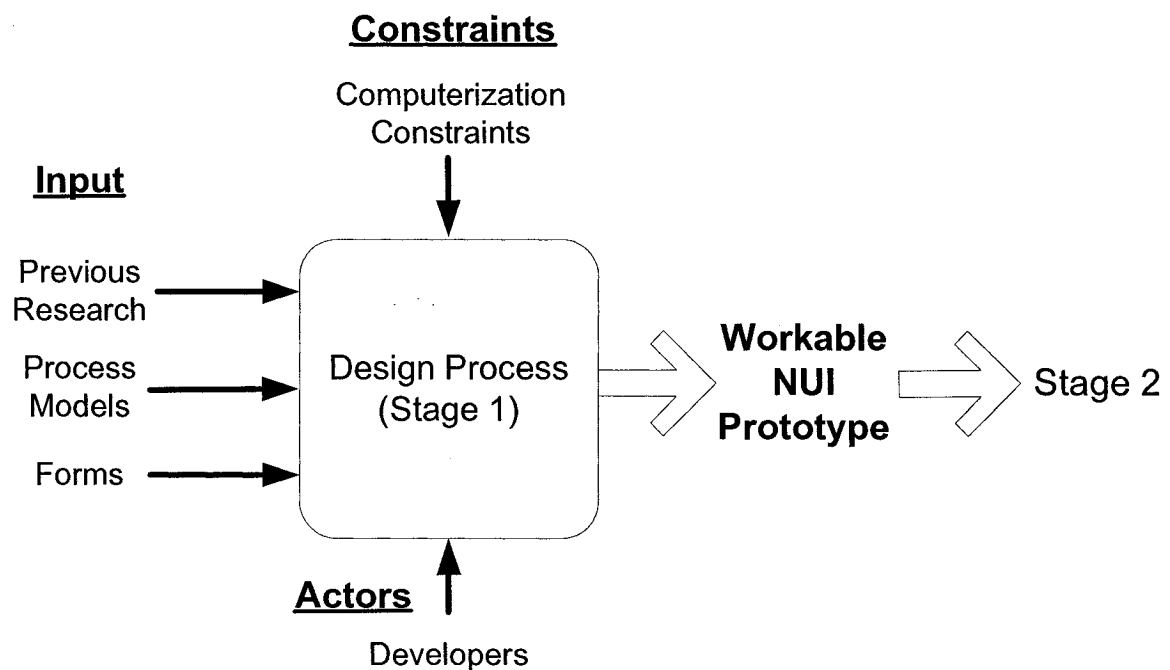


Figure 4.3 – NUI design process (stage 1)

Apart from the research we discussed in Chapter 2 involving developing software systems for healthcare, the remainder of the inputs into the first stage of the NUI design process emanate directly from or through byproducts of our ethnographic study of the organ transplant ward. These byproducts include the comprehensive process models we

created and presented in Chapter 3 and a list of the currently used hospital forms at the organ transplant ward.

In this first design stage, we spent substantial effort in understanding our inputs and constraints in order to make specific decisions regarding the development of the NUI. We started by analyzing our process models with emphasis on task analysis of the Nursing Process. From this exercise, we deduced that due to constant and dynamic switching between two different activities performed by nurses — namely, AO and FO activities — that 100% automation is inappropriate and we should focus to provide smooth transition between AO and FO activities. We believe that attempting to automate all data capture cannot be suitably integrated without rashly replacing the current practice. It is evident then, as research has indicated [107], that although the role of the paper-based recording system can be diminished, it cannot be eliminated. Thus, two systems (paper-based and computer-based) will ultimately be working in parallel to support different tasks. Although the NUI will not operate exclusively as the only information system for the ward, it will be responsible for handling the vast majority of information related to nursing activities.

Designing for Usability

In order to ensure that the NUI interface would be familiar to nurses, we tried to emulate on computer all forms currently in practice and used by the nursing staff at the organ transplant ward. By replicating the “look-and-feel” of the current paper-based system, we believed that the already well-formulated customs and habits of the nurses would make

the NUI system intuitive and easy to use⁵. In this sense, we are not imposing any mechanism of improvement but rather providing an equally capable system that offers potential for improvement. For the purposes of designing the NUI, we looked to computerize the following forms and their use (see Appendix D):

1. Nursing Kardex
2. Clinical Signs Sheet
3. Intake and Output Sheet
4. Medication Kardex (list of medications prescribed)
5. Medication Record (records of how medication is given to each patient)
6. Orders for SC Insulin Therapy
7. Diabetes Medication Record
8. Progress Sheet

Designing for Acceptability

In addition to usability, we also had to make a decision on how we would assure that the NUI would remain acceptable to all stakeholders. We uncovered, both through previous research and through our own observations, that hospital wards function on the basis of hierarchically structured and distributed clinical workflows. In addition, accountability is important at all stages. With this in mind, we decided to refine current clinical workflows (in this case the Nursing Process) to incorporate IS by employing an underlying principle which we call *Least Interruption to Workflow (LIW)*. This constraint on minimizing the interruptions to the workflow ensures that a minimal number of changes to the existing

⁵ Later on we discuss that simple emulation of the hospital forms will not be a good idea since some changes could be advocated in the present system for the betterment of all.

workflow will bring about only necessary changes as opposed to drastic measures that might attempt to overhaul current practices that are already adapted to the working needs of HCP. In addition, this will lend well to a central theme of incrementally involving the integration of IS as a means to motivate its usage and acceptance without introducing any new obstacles.

For the purposes of the NUI, we formally defined LIW as a “set of changes” or constraints. These constraints vary greatly and include primarily operating, design, and computerization constraints. Thus, by following LIW in the development of the NUI we effectively followed a set of 10 constraints (see Table 4.1) imposed on our design.

LIW Constraints	
1.	Retain current data entry practices
2.	Encourage incremental recording
3.	Support the insulin calculation
4.	Retain double-check on insulin administration
5.	Signing the medication record
6.	Replace the paper file by a laptop
7.	No PDAs
8.	User Authentication (login/logout)
9.	Support unit coordinator functions
10.	Support the work division structure of PCAs

Table 4.1 – LIW constraints for the NUI

In fact, these constraints can also be viewed as design requirements that can be categorized into functional and non-functional requirements. This list of LIW constraints was updated through the subsequent stages of our design process.

Design Framework

In order to best integrate with the existing workflow, the decision to replace patient files on nursing carts in the ward with networked laptop computers running the NUI module was deemed a practical way to avoid major modifications. The development framework would be done in the Java programming language to ensure portability and potential extension with other systems while a local nurse database in the ward would be implemented to capture all data entered through the NUI and to schedule nursing duties.

Using the hospital forms as a starting point, we began development by attempting to computerize the aforementioned eight major forms used by the nurses at the organ transplant ward. However, attempting to perform this mapping process of a physical form to an electronic edition presented many design dilemmas due to LIW:

- Structure

Paper forms are characterized by and consist chiefly of unstructured or less structured text. An electronic representation cannot provide the same flexibility. Instead, structure in a Graphical User Interface (GUI) is in the form of graphical widget elements. Consequently, decisions needed to be made to conserve screen real estate while ensuring that the essence of the forms was not lost.

- Co-location

The problem of limited screen real-estate presented a problem for some larger forms (especially the Nursing Kardex) that are wide, unwieldy, and too big to fit onto a single computer screen. As a result, the challenge we faced was in mapping

these forms to multiple screens, and supporting effective data entry and navigation.

- Accountability

By law, due to the sensitive nature of medical data, healthcare workers are held accountable for their actions. In a paper-based system, nurses sign forms to confirm their treatment actions (e.g. medication administration, recording vital sign, etc.). However, in an electronic system, this seemingly trivial operation becomes increasingly complex. Consequently, we needed to implement a strategy for accountability to ensure the NUI could meet the needs of administration.

- Access

The delivery of healthcare is contingent on the division of work among nurses and their shift duties. A patient's care is transferred from one nurse to another during the course of a day. With the removal of forms, information sharing from one nurse to another has to be through an electronic medium. This brings about new benefits as well as new challenges. At the same time, PCA's and nurses have to coordinate and share access to certain data. This needed to be resolved by implementing an access control policy within the NUI.

Following the identification of these design difficulties, it became clear that the NUI design should not be a "one-to-one" translation of the current paper-based system but rather comprises changes as a result of limitations due to computerization. In order to address these issues in a way whereby we do not violate our initial design goals, we

consulted our process models and introduced what we denote as a *Design Focus Point (DFP)*. We define a DFP as a point in time in the Nursing Process when there is a “switch” from an AO to an FO activity or vice-versa. This is depicted below in Figure 4.4 and Figure 4.5.

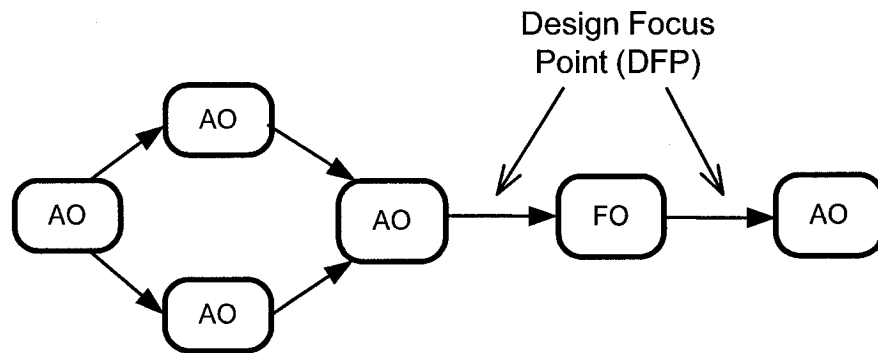


Figure 4.4 – DFPs in the nursing process

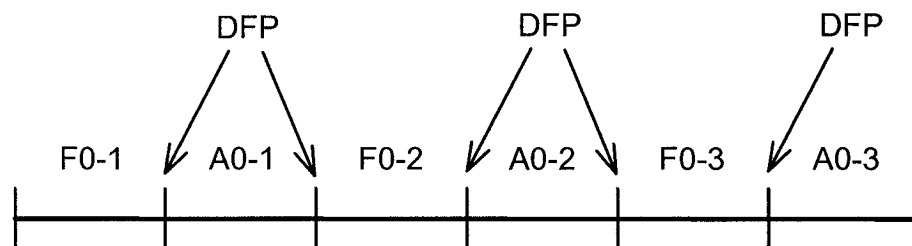


Figure 4.5 – DFPs in the nursing process

We introduce this notion of a DFP to serve specifically as a representation artifact to justify our design decisions in this initial stage of the NUI design process. According to a study that took a psychological perspective of clinical communication [13], the interrupt-driven working environment contributes to greater cognitive burdens and leads to failures of working memory to those who are immersed in such an environment. Consequently, we reason that it is at this point in time that the NUI must meet the need of nurses. The NUI should then look towards minimizing the cognitive load of nurses at each DFP that

involves switching from AO activities to FO activities or vice versa. With this in mind, we decided to address the aforementioned constraints of computerization of hospital forms using this underlying assertion. This close tie to the workflow of nurses at the DFP helps to ensure two things: (1) enhanced acceptability and (2) an intuitive interface (i.e. what I need now is right there) is provided at different points in time that requires a minimal number of keystrokes to interact with the system to support the work of nurses.

Using this reasoning for each DFP in the Nursing Process, we were able to overcome many of the challenges of computerization of the hospital forms. All decisions of grouping related items and determining the key tasks in this design stage were performed by members of the development team. Thus, as a result of many challenges and decisions that needed to be made, the first design stage of the NUI ended up taking a considerable amount of time to complete. However, within eight months, we were able to conclude the first stage of design and produce a workable prototype of the NUI.

4.6 NUI Design Process – Stage 2

The second stage of the NUI design process was when iteration and PD took center stage. It was in this design stage when we initiated direct contact with three nurse volunteers (in addition to the three participating nurse representatives that assisted in our ethnographic study) to help us evaluate and refine our current working prototype of the NUI. Figure 4.6 illustrates the second stage of the NUI design process.

At the beginning of this design stage, our understanding of the constraints faced by the nurses was incomplete. Despite significant insight revealed during our ethnographic study of the organ transplant ward, we deduced that user involvement in the design process would be imperative towards meeting our design goals. As such, during this stage of the design we relied on the principles of PD and practices of the agile software development methodology through XP to help refine the NUI. While PD helped us to directly involve the thought process of nurses in the design and creation of a better “look-and-feel” of the NUI; XP allowed us to quickly incorporate the desired changes by employing short design cycles and allowing for subsequent iterations and refinements with end-users. In addition, this approach also prevented the need to develop specialized automated function software tests since it is inherent to the design via user-based testing.

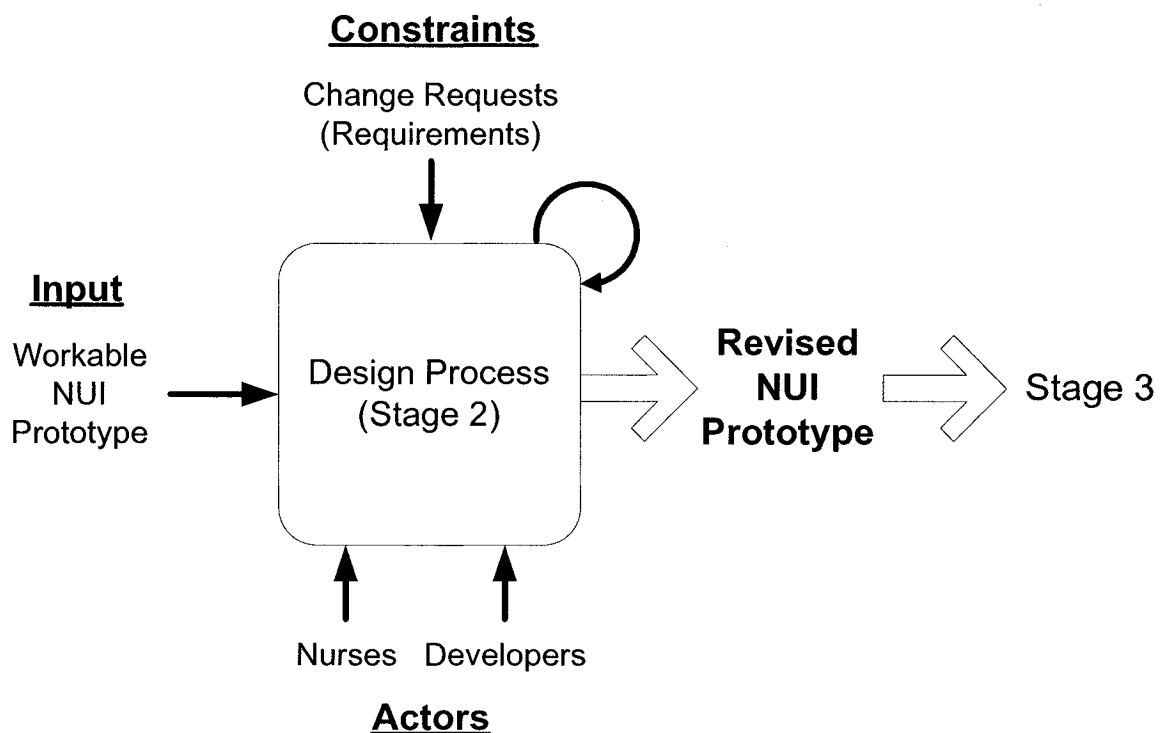


Figure 4.6 – NUI design process (stage 2)

Iterative Design Framework

In total, we needed to organize five participant meetings during this iterative second stage of the NUI design process. Of these five meetings, the first four involved the participation at least of one of our nurse volunteers on a personal level while the fifth meeting was organized as a team meeting which involved eight nurses from the transplant ward. Our objective for these meetings was to obtain an evaluation regarding the suitability of the current User Interface (UI) through user-based testing and to address and identify any omissions or incorrectness in the requirements.

The iteration involved in this design stage was a four-step process.

- Step 1

We walked the nurse participants through the NUI prototype and explained to them the logic behind our groupings of different screen layouts.

- Step 2

The nurse participants individually tested the prototype and gave feedback as to what was good and what needed improvement. These improvements came in many forms but usually either (1) clarified our misunderstanding of their practice or (2) identified novel ideas for the NUI that would greatly improve their work process.

- Step 3

We took these suggestions from the users and refined them into a set of requirements or changes for implementation. For the most part, despite continuing

to make refinements in the design, there were a significant number of changes that needed to be resolved in each of the five iterations we performed.

- Step 4

The implementation of new requirements into the NUI was addressed using RAD tools and observing the XP approach. Using the new requirements set, we first ensured that they were consistent with our design goals and that they presented flexibility that could be exploited by other nurses. Then, we employed the XP ideology to promote a short design cycle and deliver the next version of the NUI software. By doing so, we could accelerate the design process and allow for additional design iterations to ensure that the new requirements were properly captured and that development efforts matched the combined mental models of the nurses.

After we completed an iteration, we repeated this process by re-presenting the new prototype back to our nurse participants. The stages of this iteration cycle are shown pictorially in Figure 4.7.

Although XP iteration cycles vary based on customizations and different project schedules [108], our iteration cycle was an average of four weeks. This allowed us to perform five iterations to finalize the design of the NUI. Through these iterative steps of refinement, we were able to better understand the needs and constraints of the Nursing Process and how the NUI software could benefit the work of nurses.

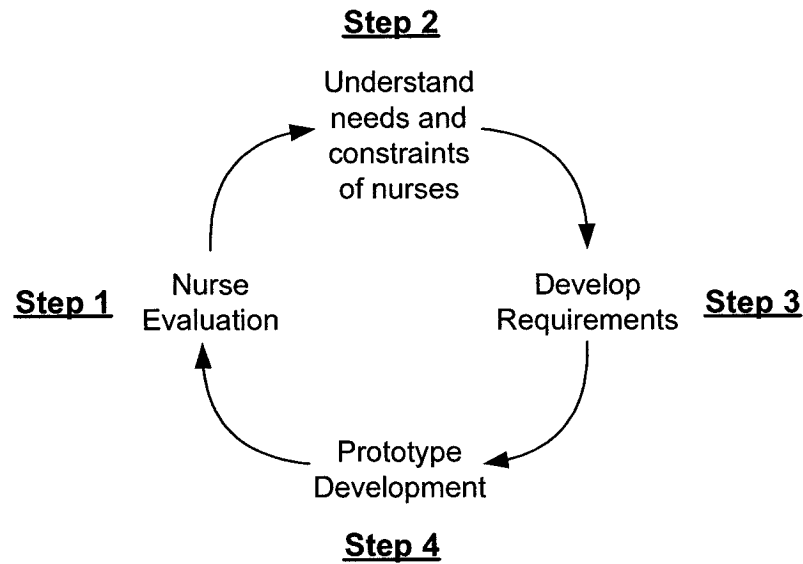


Figure 4.7 – NUI’s iterative design cycle

Challenges

Through this second design stage, we faced the common predicaments traditionally associated with UCD; namely, unclear expectations, diversity of users and suggested “left-right-center” changes. However, we also learned several valuable lessons that specifically highlight the nature of medical work and that will likely dictate the acceptance of an IS tuned for healthcare. Some of these points are further elaborated below:

- **Work habits**

There exists significant diversity in work habits among nurses and differing views on what is easy and comfortable in data collection. This implies that characterizing a typical nurse user is not a simple or trivial task.

- Standardization

Due to unpredictability in the work practice, a level of freedom in terms of structure needs to be maintained to satisfy the needs of nurses in combining AO and FO activities with dynamically varying priorities between these two categories.

- Security

A mechanism needs to be in place to ensure that sensitive patient data remains reliable and secure at all times.

- Archiving

All patient medical data is time-series based data and needs to be collected and stored in a way that facilitates easy retrieval.

- Work division

The work division among different categories of HCP needs to be adequately represented (e.g. nurses and PCAs, information access by doctors and surgeons on rounds, needs of medical students and other trainees, etc.).

At the end of this second design stage, we had refined the NUI through five software design iterations. With the final participant meeting scheduled with a team of eight nurses, our design benefited from the collective input from approximately one-third of the nurses at the organ transplant ward. As such, the group participation allowed us to converge towards a final suitable design of the NUI. Moreover, the prospect of

implementing the NUI at the transplant ward generated enormous enthusiasm. As mentioned, despite our deeply involved ethnographic study (see Appendix A), the involvement of selected nurses in this stage of the design refined our knowledge and helped us to interpret the comments and suggestions we received from many other stakeholders.

In the end, the final structural aspects of the NUI (abstractly presented in Figure 4.8) emerged. Not only were refinements made to better reflect their workflow, but nurses realized the flexibility and opportunity provided by computerization; consequently, they took the liberty to suggest enhancements to the NUI by adding new requirements to the system. One of these new requirements was the development of an *Overview Panel* indicator within the NUI that allows nurses to view essential information about all patients under their care. We learned that in their workflow practice this Overview Panel would help them to dynamically set or alter their priorities when selecting their next task. In addition, monitoring agents were also introduced in the NUI to raise attention and draw focus on items that need immediate attention. Many other innovations like automated graphing and calculations involved in insulin therapy have been introduced to assist nurses in different ways. Many of these features would not be possible or would have remained non-existent in the current paper-based system.

Overall, we note that beyond refining our initial designs to make the system more usable and acceptable for nurses, this second stage of the design process involving the PD and

XP approaches allowed us to promote the NUI's appeal by incorporating several novel changes as suggested by actual end-user nurses.

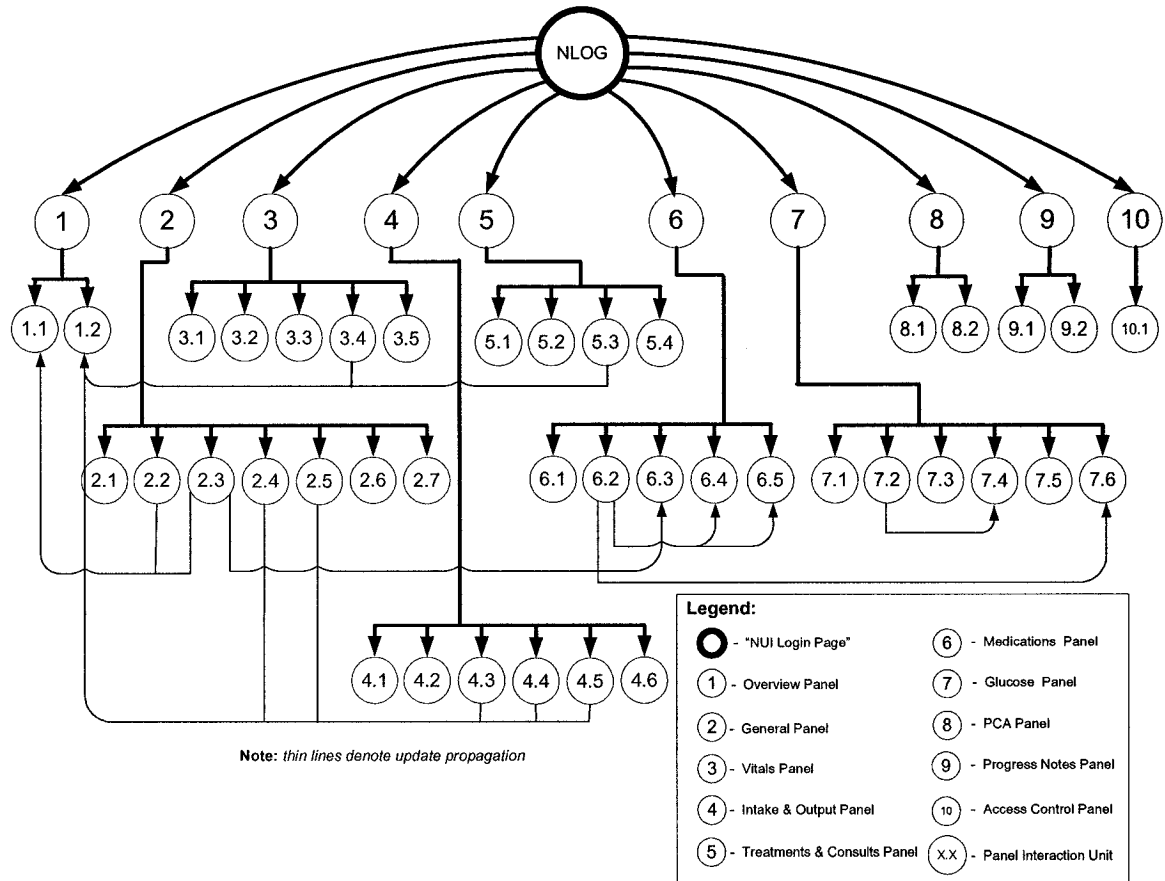


Figure 4.8 – Navigation of the NUI panels

4.7 NUI Design Process – Stage 3

With UI layout and design complete, the third and final stage of the NUI design process was concerned with data management and populating the NUI with “real” data. This involved designing database schemas to support the NUI and testing the final version with nurses as well as other involved project stakeholders. After having devoted significant efforts towards supporting the complex amount of data generated and

accessed by nurses until this point, we now directed our attention towards developing a well-organized database. With the implementation of this database, the NUI would be fully operational and could be tested in a real-life situation independent of other CIS modules. Once again, we iterated this enhanced version of the NUI with our participating nurses to ensure the system was usable. Also, we involved hospital stakeholders (including PCAs and the head nurse of the organ transplant ward) to ensure the design would be acceptable by the hospital system. Figure 4.9 illustrates the third and final stage of the NUI design process.

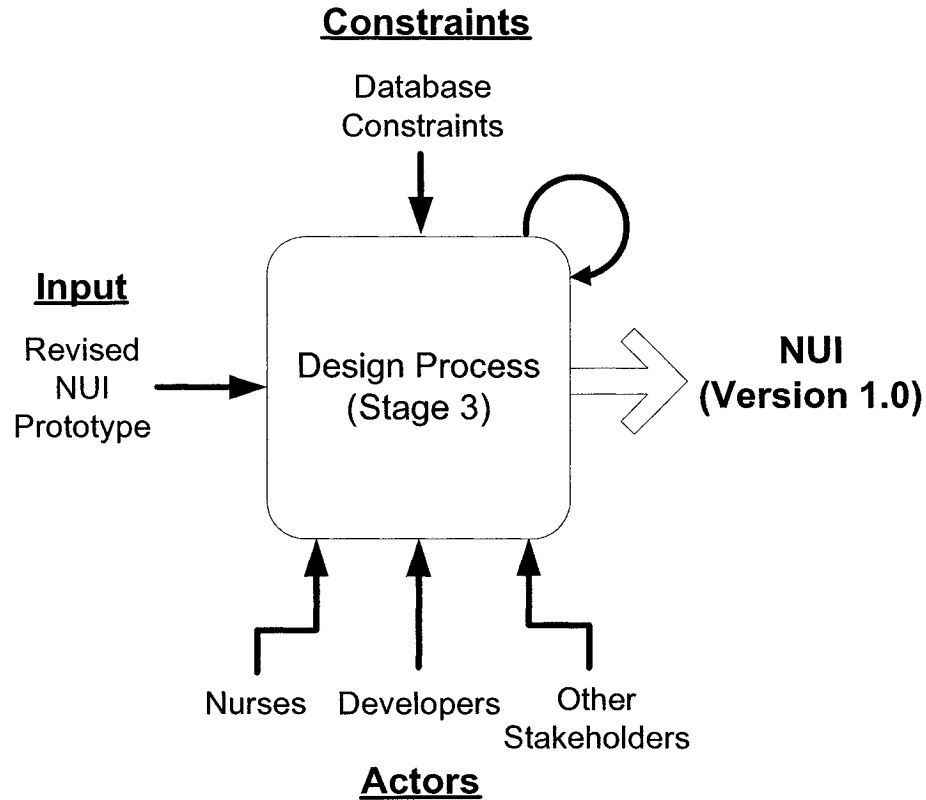


Figure 4.9 – NUI design process (stage 3)

Although the computational portion of the Nursing Process that the NUI handles is not substantial, the design of the database schemas to support the Nursing Process is no

trivial matter. The major difficulty was in ensuring that the relational database model satisfied desirable integrity constraints. These functional and inclusion dependencies played an important role in influencing the database design and helped us to determine what information should be recorded in which relation. After having converged towards a satisfactory database schema, we implemented the database and used it to drive the NUI.

After having addressed all residual errors, we demonstrated our enhanced prototype to the nurses. This prototype was fully functional and nurses were able to use the NUI to store and retrieve sample patient data as required. With the help of the nurses, we were able to identify and address several bad constraints that we had specified in our database schema and rectify them. Table 4.2 shows the final names of the relations in the NUI database schema along with a list of the active and passive entities that can update these relations. The details of the final database schema, including relation names and a complete set of attributes, is found in Appendix B.

After having finalized the database schema, we met with our other project stakeholders to ensure that the NUI satisfied their needs in a similar way. Despite several operational concerns of installing, maintaining, and operating computers on the ward, these stakeholders were satisfied with the design of the NUI. One major concern by a stakeholder was how the other hospital systems could interact with the NUI in a timely fashion. Consequently, they preferred if the NUI would operate without interference from any other external entities until other hospital disciplines (e.g. pharmacy) were more

technologically sound. We were able to eventually decipher that their major fear was the possibility of a state of data inconsistency occurring.

Relation Name	# Attributes	Initialized by:	Updated by:
hospital.admin	3	SYSA	SYSA
hospital.ambulation	8	----	NDE
hospital.consultations	5	CPOE	CPOE
hospital.daily_report	4	NUI	NUI
hospital.diagnosis	3	CPOE	CPOE
hospital.elimination	12	----	NDE
hospital.fluid_intake	9	----	NDE
hospital.fluid_output	6	----	NDE
hospital.fluid_output_sources	25	CPOE	CPOE, NDE
hospital.general	7	HIS(ADM)	NDE, CPOE
hospital.glucose_record	5	----	NDE
hospital.insulin_meds_base	7	CPOE	CPOE
hospital.insulin_meds_scale	8	CPOE	CPOE
hospital.insulin_meds_time	6	CPOE	CPOE
hospital.insulin_record	7	----	NDE
hospital.interventions	4	CPOE	CPOE
hospital.iv	8	CPOE	CPOE, NDE
hospital.med_record	6	----	NDE
hospital.medications	11	CPOE	CPOE
hospital.nurse	4	HIS	HNA
hospital.nutrition	7	DIET	DIET
hospital.other_consultations	5	CPOE	CPOE
hospital.patient	7	HIS(ADM)	CPOE
hospital.patient_nurse	2	----	HNA
hospital.patient_room	3	----	HNA
hospital.pca	4	HIS	HNA
hospital.personal_care	9	----	NDE
hospital.progress_notes	3	----	NDE
hospital.respiration	8	CPOE	CPOE, NDE
hospital.specimens	5	CPOE	CPOE
hospital.treatments	8	CPOE	CPOE
hospital.vitals	14	----	NDE
hospital.vitals_frequency	5	CPOE	CPOE
hospital.weight	4	----	NDE, PCA
hospital.xrays	5	CPOE	CPOE

ADM	Administration
CPOE	Computerized Physician Order Entry
DIET	Dietician
HIS	Hospital Information System
HNA	Head Nurse Allocation
NDE	Nurse Data Entry
NUI	Nurse User Interface
PCA	Patient Care Associate
SYSA	System Administrator

Table 4.2 – NUI database relations

Consequently, we made the necessary changes to completely decouple the NUI from all other hospital IS. After making these final changes, we froze the design and released version 1.0 of the NUI.

4.8 Summary

The design strategy of the NUI started with a process discovery approach to gain insight into the global view of ward activities. This approach then served to focus us on the Nursing Process in particular. The various steps we observed through the design process are listed in Figure 4.10.

1. Formulation of problem
2. Ethnographic study, design and execution
3. Study the list of forms used in practice
4. Perform task analysis
5. Initial storyboarding and screen design
6. End-user participation and testing
7. Refine the design
8. Repeat steps 6 and 7 until it is satisfactory
9. UI walkthrough with team of nurses
10. Database design
11. Repeat steps 6 and 7 until it is satisfactory
12. Acceptance test with other stakeholders
13. Repeat step 7 until it is satisfactory
14. Delivery of **NUI Version 1.0**

Figure 4.10 – Steps followed in NUI development

With the completion of all development changes, a typical walkthrough of the NUI is as follows:

1. A nurse logs into the NUI software system (at a glance they can view their assigned patients for their upcoming shift and in which bed and room these patients are located).

2. The NUI has ten panels and tabs corresponding to each panel are used for navigation. For example, the Overview Panel is shown in Figure 4.11 and the *Medication Panel* is shown in Figure 4.12.
3. A nurse selects one of the panels, based on need, for the purposes of information access or data entry. A facility for batched data entry for different patients is possible.
4. Each panel is subdivided into several *Panel Interaction Units (PIUs)*. The PIU's of all ten panels of the NUI are shown in Figure 4.8.
5. The Overview Panel (Figure 4.11) gives the “up-to-date” status information of a patient. Its updates are automatically handled by the NUI as new data becomes available.
6. At any time, a nurse has the freedom to switch between the patient records of any of their assigned patients to view or enter relevant patient data.

Overall, we met our objectives in designing the NUI. We were able to work in close contact with actual end-user nurses as they helped us to refine the knowledge we initially gained from our ethnographic study. In working with these different nurses, we faced the challenge of understanding the considerable variations in the way different nurses do their work; despite the fact that the tasks they perform are the same. As a result, we had an incrementally evolving model of the system that combined the knowledge of several users. This assisted our ability to interpret the responsibilities of their work practice and to see how the design of our NUI could

serve to complement their work. This resulted in, among other things, incorporating novel changes like the Overview Panel that provides nurses a facility to stay abreast of the up-to-date state of care-giving needs of their patients. In doing so, we always remained committed to usability in ensuring that these changes would remain intuitive as nurses transitioned to the use of the NUI in their work practice.

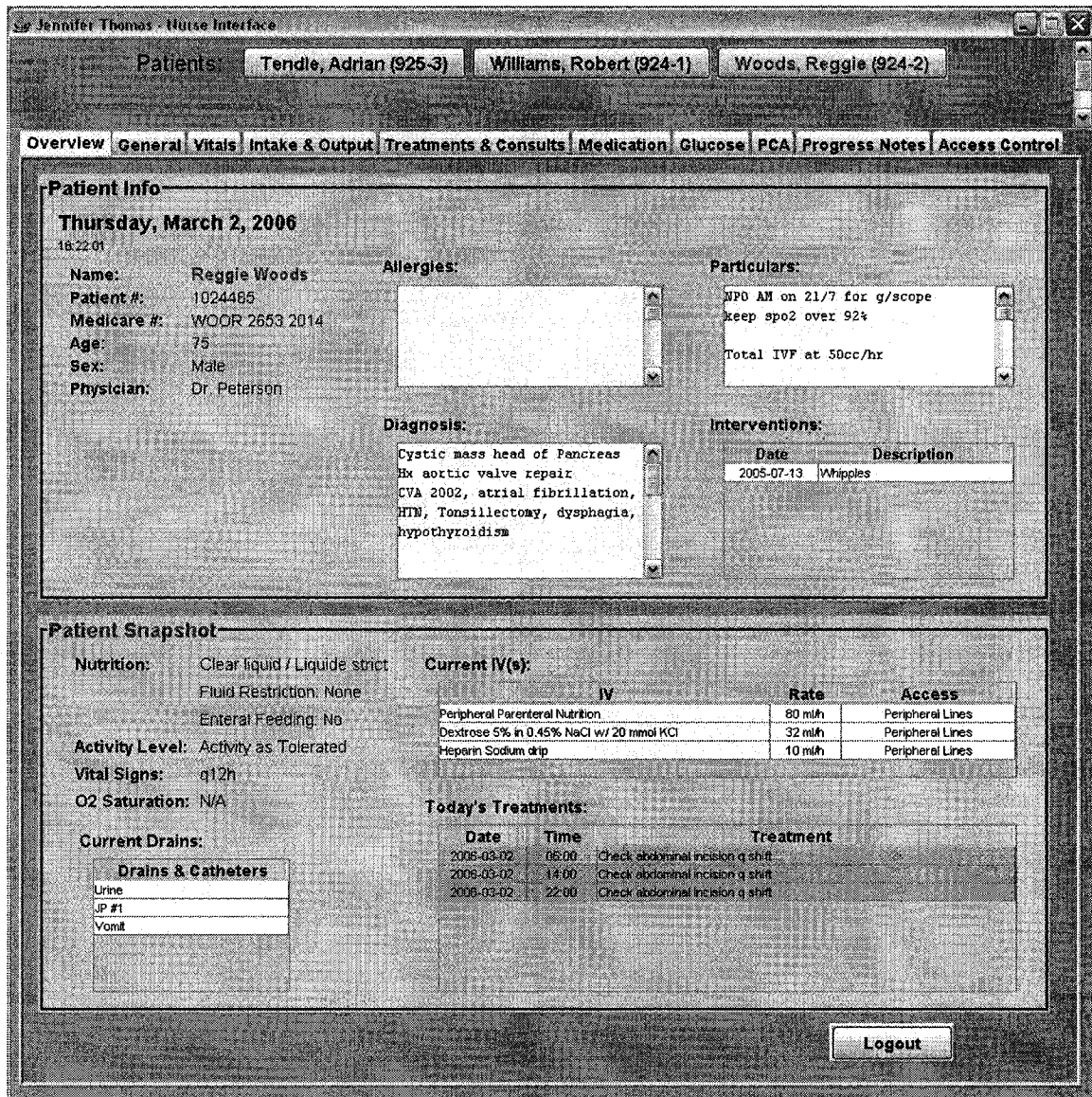


Figure 4.11 – NUI overview panel

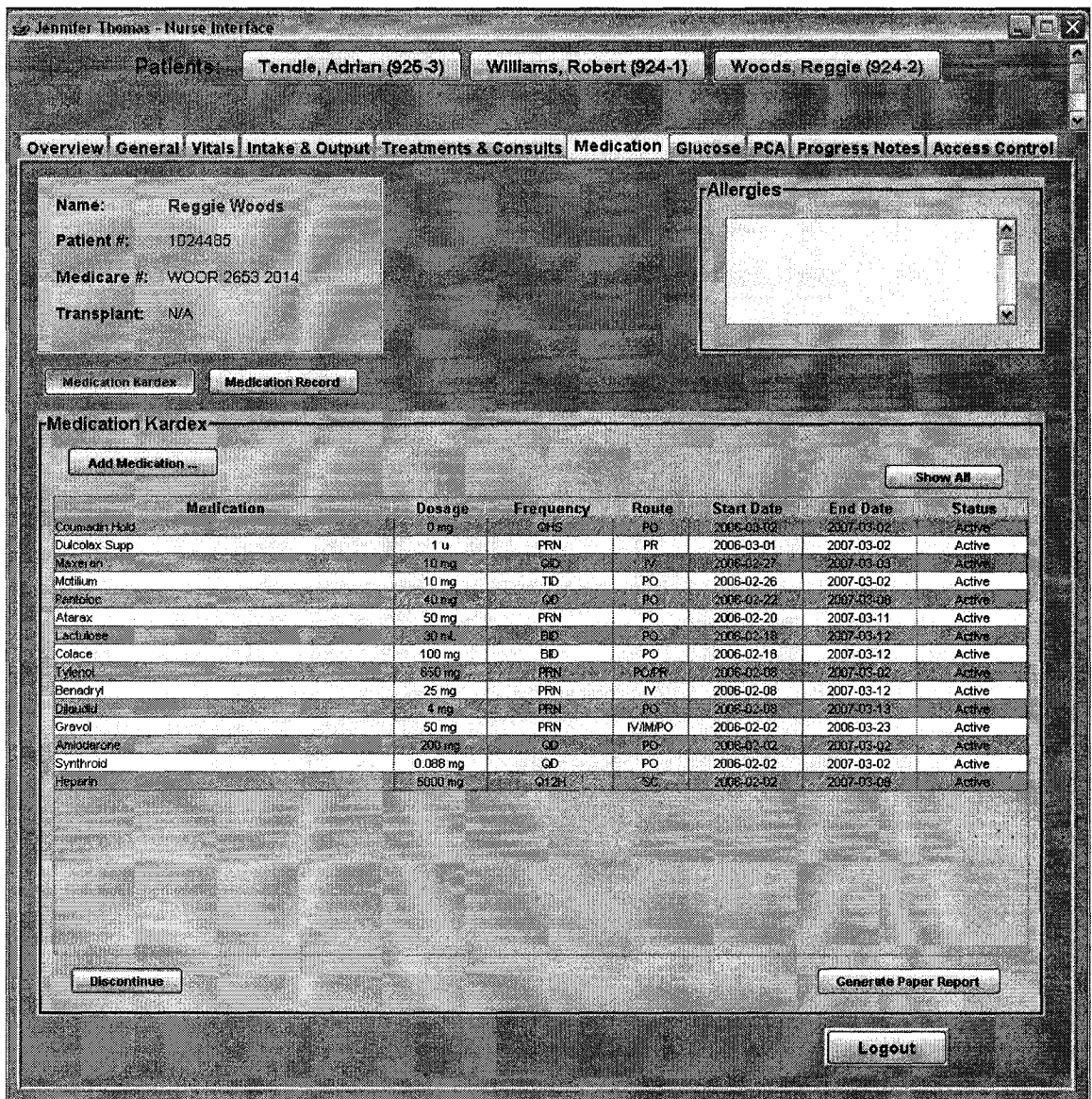


Figure 4.12 – NUI medication panel

Through our design of the NUI software system, engineering the UI was undoubtedly our biggest challenge. We started with the paper-based record system as a design paradigm to promote acceptability by retaining information sharing and data entry practices. However, in order to meet limitations and enhance the power of computerization, we made modifications through our iterative design approach with nurses to satisfy constraints, address redundancies and inefficiencies, and introduce changes for the

betterment of all. This required, above all, the understanding of the underlying processes to determine what is essential to nursing care. In the end, we designed a system well-tuned to the working needs of nurses that considers such logistics as the frequency and priority of nursing tasks that we believed would improve their work practice by incorporating a usable and acceptable IS for them as well as other involved hospital stakeholders.

In the following chapter, through the design and execution of a field-test, we will test our beliefs to determine if the NUI has indeed succeeded in meeting our design goals.

Chapter 5

Experimental Evaluation: The NUI Pilot Study

To date, we had based the measure of success of the NUI on two criteria: (1) Continuous evaluation by the three different nurses who participated in the development and testing stages. This evaluation was not statistically based but rather on interviews, qualitative judgments, and comments. This evaluation is biased to some extent since the participating nurses were continuously involved in the development process. (2) Evaluation and stress-testing carried out by members of the design team. Again, this was a qualitative evaluation. Our NUI product has passed these two evaluations successfully.

Despite passing these initial evaluations, there was significant reason to believe that our assessment of the NUI was lacking a crucial element associated with a “good” study design. Moreover, we were unable to provide any quantitative results from our evaluations that we would be able to use to advocate to funding bodies and other stakeholders that this study is worth endorsing. Since the NUI was designed as a testable standalone module, we decided to test it by conducting a field- test at the organ transplant ward. We would conduct our field-test as a pilot study, or a mini-version of a full-scale study, involving actual end-user nurses using live patient data in a real hospital environment. Although a pilot study would not be able to guarantee 100% success of our study, it would increase the likelihood and its outcomes would be of valuable insight for us as designers and of particular interest to stakeholders.

Consequently, we conducted a pilot study at the organ transplant ward of a large metropolitan hospital which participated with us in the design of NUI. In the end, our pilot study involved some 10 different nurses and 4 PCAs spread over 10 shifts, totaling more than 50 hours of operation, spread over three days. For quantitative evaluation by participants in the pilot study, we used a questionnaire based on the standard SUMI used in usability studies [109]. Our overall conclusion from the pilot study, with regard to our two major objectives, was extremely favorable and highly encouraging. The progression of our pilot study (as shown in Figure 5.1), the techniques used for evaluation, and a discussion of lessons learned are reported in the following sections.

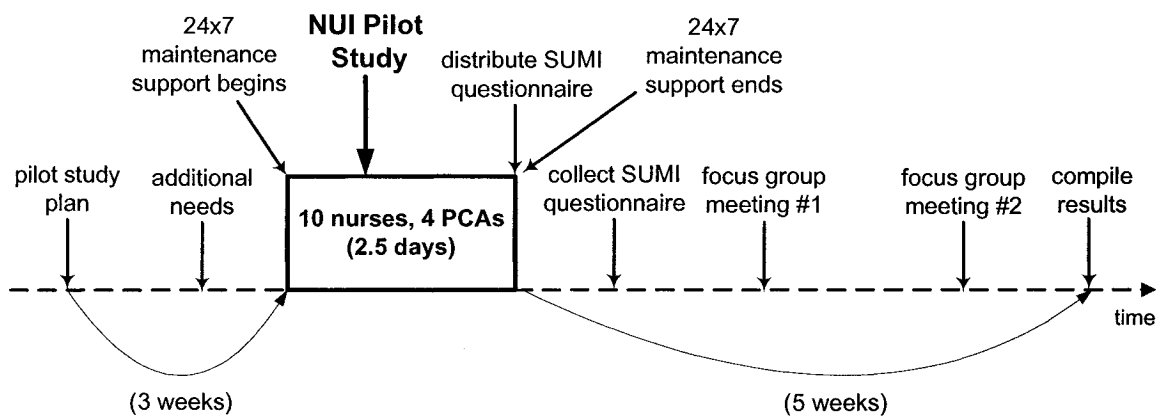


Figure 5.1 – Progression of the NUI pilot study

5.1 Clinical Environment

Our pilot study took place from July 19th to July 21st 2005 at the transplant ward of a major metropolitan hospital. This ward treats approximately 520 patients per year in its 25 bed facility intended for recovering organ transplant patients. On average, a patient's length of stay in this ward is 13 days. A total of 30 registered nurses, 10 physicians and a large number of consultants (cardiology, respiratory, endocrinology, infectious diseases, psychiatry, rheumatology, pain service, gastrointestinal and neurology) were working on the ward during the study.

5.2 Study Design

5.2.1 Study Aims

We set two aims for this pilot study:

1. To study the following usability factors of the NUI:
 - a. Learning time
 - b. Look-and-feel
 - c. Ease of use
 - d. Robustness
 - e. Functional completeness/incompleteness as faced in usage
 - f. Operation issues in the real world situation

2. To study the reactions of the nurses to the use of IT in this nursing-intensive ward that deals with transplant patients (kidney, liver, pancreas, kidney-pancreas, etc.).

5.2.2 Study Plan

In order to plan a proper pilot study of the NUI, we addressed three major criteria:

1. Population size and timing

In order to provide realistic results, we felt the study group of nurses and PCAs involved in the NUI pilot study should consist of roughly one-third the nursing workforce of the transplant ward. Carefully planned scheduling changes in nursing duties needed to be made to accommodate the pilot study. In addition, the NUI had to be capable of handling such dynamic conditions as new patient admissions and discharges during the shift duty of a nurse.

The details of the NUI pilot study trial environment were finalized as follows:

- 10 nurses and 4 PCAs
- 57 hours of operation
- 10 shifts spread over 2.5 days
- 10 inpatients

2. Fitting the pilot study in the clinical environment

We identified three different possibilities:

Type 1: The NUI would co-exist along with the current (manual) practice (see Figure 5.2). However, this would effectively duplicate the efforts of nurses and PCAs throughout the duration of the pilot study.

This approach was not chosen because it required too much additional work for nurses and presented highly unrealistic conditions that we believed might negatively influence the results of the pilot study.

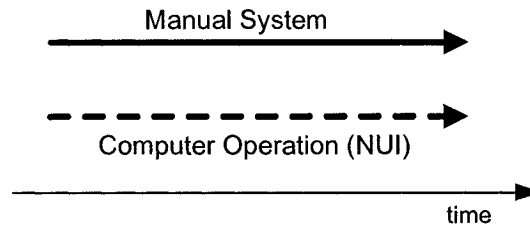


Figure 5.2 – Pilot study in parallel with manual system

Type 2: The NUI would completely replace the current (manual) system for the three-day trial period (see Figure 5.3). This would require a well defined protocol for “transitioning-to” the NUI and “transitioning-back” from the NUI.

This approach was not chosen because the nurses did not initially have 100% confidence in the NUI.

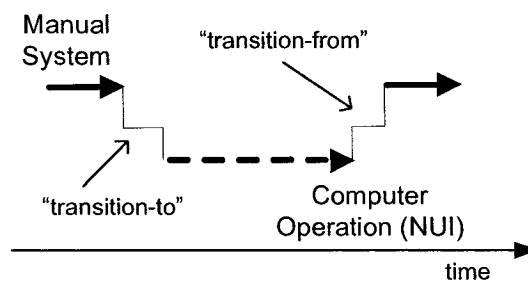


Figure 5.3 – Pilot study excluding manual operation

Type 3: The NUI would exist in selective conjunction with the current (manual) system to ensure safe and smooth operation (see Figure 5.4). This would require special attention to ensure that data remains both complete and consistent inside the computer and in print. Diabetic management, for instance, which is critical for transplant patients, would be duplicated both under the NUI and in the manual method.

This approach was chosen for the NUI pilot study.

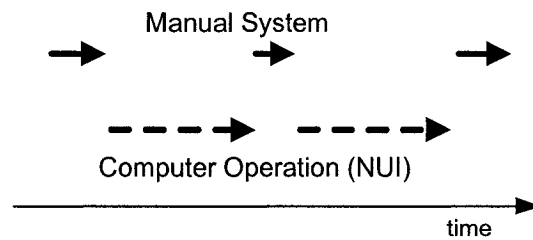


Figure 5.4 – Pilot study in combination with manual system

3. End-user training

User training is an important requirement when embarking on a pilot study. In fact, when many users are involved, training is a non-trivial problem. We started by creating a detailed user's manual [110] to serve two main purposes: (1) to provide insight into the goals of our research, and (2) to assist in the training process for the NUI pilot study.

We used a two-tier approach to training. We started by first identifying a nurse practitioner as our “champion” and trained them in using NUI on a one-to-one basis. This proved to be very helpful as they quickly became an expert in using

the NUI and inspired other nurses in learning and training. Following the education of our champion, we used their help along with the NUI user's manual to conduct three training sessions on the days prior to the start of the pilot study. These training sessions involved nurses and PCAs scheduled to participate in the study. Each training session lasted an average of about an hour where participants received a personal copy of the NUI user's manual and were given a "hands-on" tutorial on how to use the system with real data.

5.2.3 Additional Needs

Before conducting the pilot study, we had to address several additional needs. While the majority of these needs required the introduction of new features into the NUI, others were decisions made to improve the likelihood of success of the pilot project.

1. Administrator interface

In order to provide proper support for the NUI in its deployment into a real-world work environment, the creation of an administrator interface became essential. This interface, to be used only by selected authorized users during the course of the pilot study, would provide a facility to change access control permissions. This would include, among other things, adding users authorized to use the NUI, handling password management issues and assigning patients to nurses at the start of a new work shift. In addition, this interface would provide an ability to admit and discharge patients as well as be able to assign them to different rooms and beds within the ward. In a global sense, the interface would ensure that the NUI

could adapt, on a need basis, to the changing working schedule of nurses and PCAs in the transplant ward.

2. The “coffee break” feature

In an organ transplant ward, it is imperative that a patient be under the care of a nurse at all times. Consequently, in the current system, when a nurse takes a “coffee break” her patients are temporarily assigned to the care of another nurse currently on duty. In order to handle this particular characteristic of a non-stop system, the NUI would need to allow nurses to temporarily assign their patients to another nurse on duty while they went on break. This temporary assignment would give the newly appointed nurse full access to the necessary electronic patient records.

3. Printing backups

In order to ensure that nurse accountability is maintained throughout the duration of the pilot study, the NUI would need to provide a facility for paper reports to be printed at the end of each nursing shift (to be signed by the nurse responsible to those transactions). These paper reports would be formatted in an identical fashion to the current paper-based forms (used in the ward) so that they can be seamlessly integrated into the patient’s file. This mechanism is necessary since the current version of the NUI does not yet incorporate digital signatures.

4. Data initialization

Having decided to involve 10 patients in the NUI pilot study, we would need to perform the non-trivial task of initializing relevant relations in the NUI database by populating it with “real-data” pertinent to these patients. Since this data is constantly changing (by the minute/hour) in the real-world, this initialization process is neither a trivial nor a minor task.

5. Maintenance support

Throughout the duration of the pilot study, two members from our team would provide 24-hour on-site maintenance support. The support would involve answering any questions by the nursing staff and taking hourly data backups. We believed this sort of around-the-clock support would provide nurses with the confidence to accept and embark on the pilot study.

Thus, in order to meet the needs of the pilot study, we needed to make several additional modifications to the NUI’s design. As such, we effectively initiated a new stage in the NUI design process. This fourth design stage was once again an iterative development stage that involved consulting our nurse participants as well as our champion once the changes to the NUI were completed. The result from this fourth design stage, as shown in Figure 5.5, resulted in a new version of the NUI software as well as the *NUI Administrator* software that would be used during the pilot study.

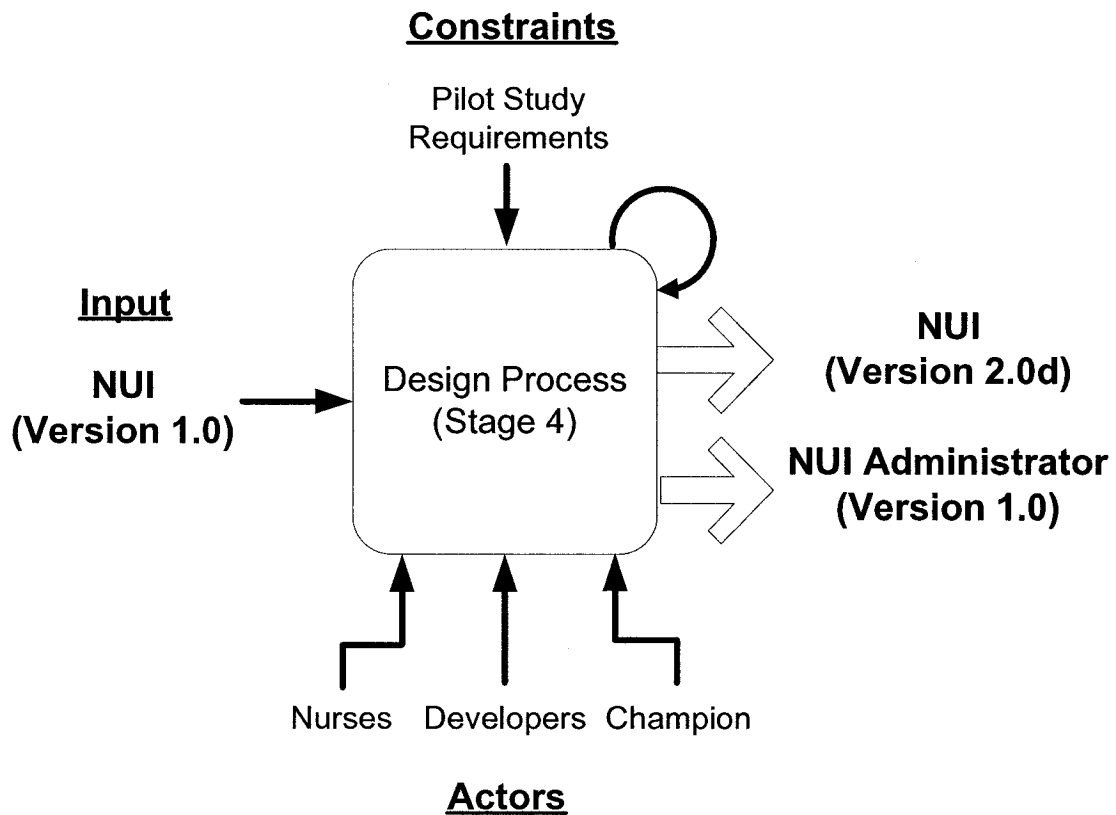


Figure 5.5 – NUI design process (stage 4)

5.2.4 Hardware Requirements

In order to accommodate our pilot study, the organ transplant ward was equipped with two laptop computers complete with external mice and flat panel monitors. The decision to use laptop computers over traditional desktop machines was prompted by the desire to conserve as much space as possible. These laptops computers were installed on top of two nursing carts in the ward and networked together using a client-server architecture. The former would help ensure the NUI could seamlessly fit into the current workflow of nurses while the latter would ensure the two laptop access points share a common database to prevent any data inconsistencies. In addition to the laptops access points, a printer was connected to this network to allow printing paper backups from the NUI.

5.3 Evaluation Methods

We have used the following evaluation methods to assess the impacts of the NUI pilot study. We present them below in order of decreasing importance.

1. SUMI questionnaire

Following the completion of our pilot study, we asked each nurse participant to anonymously complete a questionnaire. This questionnaire was based on the de facto industry standard Software Usability Measurement Inventory (SUMI) evaluation questionnaire used for assessing the quality of use of software by end-users. It comprises a set of 50 carefully chosen questions that have been rigorously tested and proven to effectively measure software quality from the end-user's point of view. We used a specialized SUMI profile analysis statistical software package to analyze the results.

2. Focus group meetings with end users (2 meetings)

In addition to SUMI, we also wished to obtain an analytic evaluation of the NUI software. As such, we organized two focus group meetings in the weeks following the NUI pilot study. Since all the participants could not attend a single meeting, we scheduled two focus group meetings:

- First meeting - 2005/08/02 (7 participants)
- Second meeting - 2005/09/07 (5 participants – 2 repeat participants)

During these meetings, we reviewed comments that were recorded in a logbook during the pilot study where participants wrote comments and problems they

faced while using the NUI. We collected this list and interacted with our participants to gain better insight into the motivation behind these comments and suggestions. In addition, the focus group members were encouraged to speak freely about their feelings while using the NUI software - about their experiences (positive or negative), wishes for future versions, etc.

3. Informal/spontaneous comments

These impulsive comments by nurses and PCAs were collected by members of the design team during the pilot study.

4. Comments by stakeholders

In a similar way, impulsive comments by stakeholders were also collected during the pilot study by members of the design team.

Overall, we placed a greater importance towards the SUMI evaluation since it was our only evaluation of the NUI software that could provide us with quantitative results. Our three other evaluations methods, on the other hand, could only provide us with qualitative feedback regarding the NUI.

5.4 Results

5.4.1 SUMI Results

The 50 questions from the SUMI evaluation questionnaire [109] cover six scales (Efficiency, Affect, Helpfulness, Control, Learnability, and Global) that help to evaluate software. *Efficiency* indicates the participant's perception of their efficiency; *Affect*, how

much they like the product; *Helpfulness*, how helpful they found it; *Control*, whether they felt in control; and *Learnability*, the participant’s perception of ease of learning. The *Global* scale, on the other hand, is a highly reliable general usability “temperature” metric; its usage is generally restricted to when there is a need for a single, global, user-derived value to give an overall indication of satisfaction. Each of the six scales, including the Global scale, is measured on a score out of 100.

The automated *SUMISCO* software package takes the raw scores from these questionnaires, compares them with specialized normative tables, and provides a standardized output distribution for the six scales. These results for the NUI are shown in Table 5.1.

Number of participant nurses (n = 10)

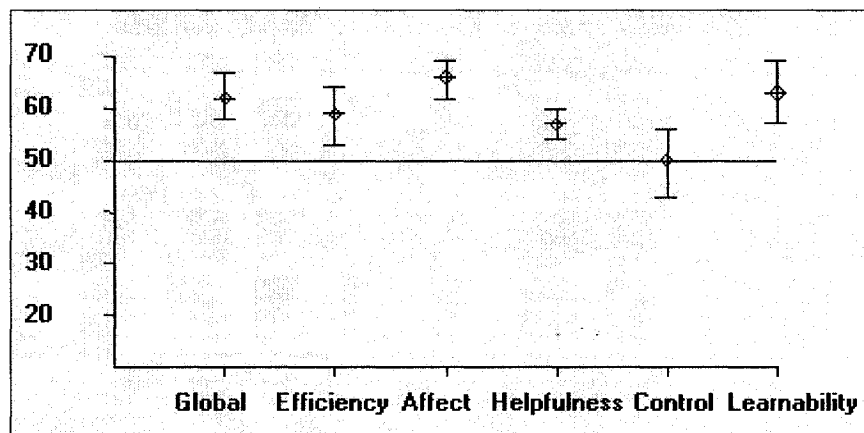
Scale	UF	Ucl	Medn	Lcl	LF
<i>Global</i>	74	67	62	58	44
<i>Efficiency</i>	81	64	59	53	36
<i>Affect</i>	75	69	66	62	56
<i>Helpfulness</i>	69	60	57	54	42
<i>Control</i>	81	56	50	43	21
<i>Learnability</i>	76	69	63	57	52

Table 5.1 – SUMI profile analysis of the NUI

As indicated above in Table 5.1, each SUMI scale is scored against five values:

- *Medn* corresponds to the *median*. It is the middle score when the scores are arranged in numerical order. It is used as the primary indicative sample statistic for each usability scale since it is quite “resistant” to outlying observations (see Figure 5.6).

- *Ucl* and *Lcl* are accordingly the *Upper and Lower Confidence Limits*. They represent the limits within which the theoretical true score lies 95% of the time for this sample of users.
- *UF* and *LF* are the *Upper and Lower Fences*. They represent values beyond which it may be plausibly suspected that a user is not responding with the rest of the group — the user may be responding with an outlier.



Legend

- $Scale \geq 60 \rightarrow$ characteristic of “good software”
- $Scale \leq 50 \rightarrow$ poor usability
- $Scale \leq 40 \rightarrow$ immediate remedial action required

Note: Industry average SUMI score is 50 for all scales

Figure 5.6 – SUMI profile analysis of the NUI with 95% confidence intervals

Interpreting the SUMI result data, we observed that NUI has no median scores below 50 across any scale. Moreover, the Global, Affect, and Learnability scales all have median scores greater than 60. Although the Control scale has a median value of exactly 50, we point out that the NUI was not designed to give the user extensive control but rather designed to follow and support the workflow of nurses. Our belief was such that too

much control in the hands of end-users would make the system intimidating to use and would therefore make it unusable.

From the SUMI test guidelines, there is a built-in measure to ensure that our data set was well collected and came from a homogeneous group sampling. This was verified by examining that the difference between the 95% confidence levels (Ucl and Lcl) is less than 10 for each scale. In our case (as seen in Table 5.1), Affect, Helpfulness and Global all have a difference in confidence levels of less than or equal to 10. Since our sample size was small (n=10), ranges slightly greater than 10 for the confidence interval is acceptable. Thus, we have at least a moderate assurance that our data set for the NUI is well collected.

In order to compute the above-mentioned SUMI profile analysis, the raw score for each nurse participant was first computed. Shown below in Table 5.2 are the raw scores of the 10 nurse participants that completed our SUMI questionnaire.

Nurse #	Global	Efficiency	Affect	Helpfulness	Control	Learnability
1	44	40	62	51	35	58
2	64	66	66	60	47	66
3 (HL)	43	38	48	41	41	41
4	54	51	56	60	40	61
5	67	65	71	57	65	68
6	66	69	71	53	61	69
7	63	71	68	51	62	71
8	52	57	53	42	48	62
9	62	60	66	57	51	64
10	62	53	66	60	61	60

Table 5.2 – Individual SUMI user scores

The (HL) tag next to nurse #3 indicates that in the scales of Helpfulness and Learnability the scores computed from the responses provided by this nurse participant are outside the interval formed by the “Upper and Lower Fence”. Although it is traditionally a good practice to meet with participants that have scores outside this interval, our SUMI questionnaire was conducted anonymously.

Below, we summarize and interpret the median score for each of the six scales from our SUMI profile analysis of the NUI:

- Efficiency

Degree to which the user can achieve the goals of his interaction with the product in a direct and timely manner.

Efficiency = 59. Above-Average Efficiency.

Except for rare cases, the NUI supports and helps users in their work; it works in a predictable and consistent manner.

- Affect

How much the product captures the user’s emotional responses.

Affect = 66. High Affect.

Users enjoy their sessions with the NUI. They find it stimulating to use and it is satisfying and attractive.

- Helpfulness

Extent to which the product seems to assist the user.

Helpfulness = 57. Above-Average Helpfulness.

The NUI communicates clearly and users understand the way it works but it sometimes lacks giving information consistently to help users recover from mistakes.

- Control

Degree to which the user feels they, and not the product, is setting the pace.

Control = 50. Low Control.

Users feel they might get stuck with the NUI. Consequently, they feel safer if they only use those parts of it they know will work.

- Learnability

Ease with which a user can get started and learn new features of the product.

Learnability = 63. High Learnability.

The NUI is easy to get into, users could start working with it right away, and whenever a user needs to do something new, it is not a problem.

- Global

Highly reliable general usability metric.

Global = 62. High Global.

Overall, the NUI is good quality software in terms of basic usability metrics.

5.4.2 Results from Focus Group Meetings

There were a total of 41 comments that were collected from the logbook during the pilot study. Of these, most were in the form of suggestions to further improve the NUI. Upon interacting with our participants to gain better insight into the motivation behind these comments and suggestions, we classified all 41 of them into five categories:

1. Incompleteness in the NUI software

Although we involved three different nurses during the design stage, several requirements from the current practice were omitted when developing the NUI. We rationalize that these activities are second nature to nurses and removing them from their practice and asking them to formalize their work made them overlook these requirements.

2. Improvements to the data views provided by the NUI

The sorting of lists (especially medications) within the NUI could be improved to be made more useful and effective for nurses.

3. Programming bugs

Only a single programming bug was identified during the three-day pilot study — it caused the NUI to temporarily freeze on one occasion.

4. Late realizations

During database initialization, we found certain shortcomings but did not have time to fix them as the pilot study started within hours of these realizations. These

shortcomings were mostly in the form of invalid assumptions made by the database schema.

5. Access control improvements

These improvements were diverse and were related to enhancing all of the following: privacy, security, backups, fault tolerance, frequent login-logout, etc.

Following this analysis and presentation of comments and suggestions from the logbook, the focus group members shared with us their feelings while using the NUI software. This included anything and everything related to their experiences using the software. The following are paraphrases of the comments we received during these free discussions. They are listed below in no particular order.

- *“It was very easy to use. Using the keyboard for data entry was not a problem.”*
(one nurse mentioned at the beginning of the pilot that using a keyboard would be a problem for her since she is a two-finger typist)
- *“I could learn to use the NUI very easily. It was quite intuitive.”*
- *“The information I needed was available at my fingertips. This saved my running around.”*
- *“I could do charting much more easily and effectively.”*
- *“It was very easy to switch from one patient to another. I liked it.”*
- *“I could do charting in an incremental fashion and save my time for other things near the end of my shift.”*

- *“I wish I did not have to do charting in the hallway. We need computer access elsewhere for this.”*
- *“At times, recovering from errors was a bit difficult. We needed [local champion or a member from the design team] to help us.”* (by errors they meant the system freezing, or advanced editing functionalities which was not made available in this version)
- *“In charting, I use special abbreviation symbols (say 10 to 20 of them). I could not find them on the keyboard. Managing without it was a bit of a problem.”*
- *“I wish I had a PDA with wireless access to enter data while I’m on the move.”*
(this viewpoint was not shared by many, different views existed on this topic.)
- *“Every time I left the computer to go to the patient, I had to remember to logout and then I had to login again when I returned. Several times in a shift...is there a better way?”*
- *“I have to print the things I did in order to sign my work. That’s a lot of paper! Is there a better way?”*
- *“[Access control] needs better planning. Doctors must have access and other authorized people must also have access to the information we write. Access to read and selective access to modify.”*
- *“When is the NUI software coming back permanently to the transplant ward after changes to it have been made?”*

5.5 Discussion

All of our evaluation methods revealed an overwhelming positive attitude towards the NUI pilot study. The participants were satisfied and very much pleased with the capabilities of the NUI software system. They felt that the NUI was simple to use and easy to learn. They believed it was easy to learn because: (1) it was straightforward to use, (2) it did not present any surprises, (3) it was easy to understand, (4) what they needed was readily available to them, and (5) the training and the local champion were extremely helpful.

In addition, the pilot study helped to discover several innovative benefits of the NUI:

- Switching between patient files to access information was seamless as opposed to “running” to locate the actual physical files. This saved nurses a considerable amount of time and effort.
- The NUI support for medication administration and patient charting provided a significant time-savings.
- The Overview Panel helped nurses to constantly monitor and stay up-to-date with important and relevant patient information.

Along with these benefits, there were also four notable avenues of improvement identified during the NUI pilot study:

1. We identified certain functional changes that can make the NUI even more user-friendly. These changes involved enhancing both data views and options for data entry.
2. The NUI still contains at least one minor programming bug that was identified during the pilot study that caused the system to freeze once temporarily. Although other bugs existed, these were logical bugs and were a result of incorrect requirements specification.
3. In the final system, certain adaptations have to be made to make the NUI more operationally convenient and secure. This might include refining the login mechanism to involve personalized ID-cards.
4. The NUI needs to implement a policy to manage digital signatures.

Also, in addition to the 50 standardized questions from the SUMI questionnaire, we included six additional questions (see Table 5.3) to allow us to better interpret the results from the pilot study with insight into the background of our participant nurses.

User Profile Questions	Agree	Undecided	Disagree
<i>I often use a computer</i>	6	2	2
<i>I have used software system similar to the NUI before</i>	1	1	8
<i>Before using the NUI, I knew how to enter and edit data</i>	4	3	3
<i>I have used the Internet before</i>	8	1	1
<i>The training sessions helped to learn how to use the NUI</i>	9	1	0
<i>Through usage, my confidence in the NUI gradually improved</i>	7	3	0

Table 5.3 – Pilot study user profile analysis

From the obtained qualitative and quantitative results, we conclude that the NUI is a well-designed and high-quality software product. The system was used willingly throughout the pilot study and received approval from all major stakeholders. Our design strategy to model the NUI based on the current practice proved worthwhile and allowed us to meet our design goals of usability and acceptability. Although we were unable to provide quantitative data to indicate that the NUI does indeed satisfy our LIW assumption, we reason that the time savings exhibited by the nurses serves as logical argument to satisfy this claim.

Chapter 6

Conclusion and Future Work

6.1 Summary and Conclusion

This thesis has addressed a real-world problem in a healthcare setting. It involves the computerization of the nursing process in a transplant ward of a major metropolitan hospital. After studying the various related processes, we selected one component of a CIS; namely, the Nursing Process. The selected process was studied in further detail to understand the complexities and user requirements involved in creating computer-based assistance for the Nursing Process. It should be noted that the Nursing Process involves both patient care activities and information-oriented activities which involves, among others, data generation, access, and sharing in a timely fashion. As a result, this process cannot be completely automated.

There currently exist several vendors and software products in the market for healthcare support. These products have been met with mixed reviews; some of them are unsatisfactory while others are satisfactory in certain ways. We undertook this study to examine if following an appropriate software development methodology could make a difference in the development of an end-product for nurses. Our first finding was that understanding the healthcare process is a complex activity and process modeling or

workflow modeling could be of great value in this regard. We found this to be in accordance with the findings from other researchers in this field [42, 48, 49, 54, 55].

In the development of the NUI, we considered two categories of needs: UI needs for the assistance of the software product and the needs of the work environment. The former helps ensure that the software end product is both usable and useful while the latter helps ensure that the product is acceptable in the target environment. We applied the well-known software engineering principles of workflow modeling, UCD through PD, and agile software development through XP in the development of the NUI. Our fusion of these three philosophies allowed us to devise a rapid iterative design process. In doing so, we focused our efforts towards understanding the constraints of HCP and ensuring that product development continued on a path that matched their needs at every stage. Using this mindset, we systematically developed the NUI software.

Since this thesis entails engineering a software product for a real-world problem, its value is visible only if the end product is tested in a real environment by real end-users. Thus, after developing and thoroughly lab testing the NUI with our participating nurses, we designed a pilot study for field testing. As per this study, NUI was field-tested at a hospital ward with HCP over a three-day period. During this time, the NUI was used continuously to do work in a non-stop manner with real data. The usability study evaluation conducted on the NUI as a part of this pilot study has shown that the product was considered by its users to be easy both to learn and use.

For evaluation of the NUI, we used the de facto industry standard SUMI user satisfaction questionnaire. According to this evaluation scheme, a score greater than 60 is said to be an indicator of good quality software in terms of usability metrics. On five of the six usability scales, namely *Global*, *Efficiency*, *Affect*, *Helpfulness* and *Learnability*, we observed scores within a range of 57 to 66. The sixth scale however, namely *Control*, only had a score of 50. As per our design requirements, we reason that this low score was expected since we deliberately restricted software control of the NUI. The overall rating received from the SUMI evaluation was a *Global* median score of 62. In addition to this quantitative evaluation of the NUI, qualitative analysis was performed through two focus-group meetings and interviews with expert transplant nurses. Results from these evaluations indicate that the NUI was well received by nurses and helped provide an opportunity for time-savings in terms of the nursing documentation task.

The contributions of this thesis are:

1. The creation of a comprehensive workflow model composed of interacting processes applied to a specific hospital situation.
2. A systematic methodology to design a component of CIS based on the principles of agile software development and UCD.
3. Implementation of a usable software product (NUI) capable of being deployed at the transplant ward of a target hospital.
4. Performance evaluation of the NUI through an organized pilot study in a real-world setting.

As we have noted from this particular research experience, we conclude that involving healthcare professionals in the iterative development and refinement of software products intended to support clinical practices in healthcare certainly seems to have a positive impact. However, for such an approach to be practicable, we need the cooperation and full participation of well selected end-users. Although having end-users participate in the UCD process is difficult to practice, particularly with overworked healthcare professionals, a software product developed in this fashion brings other intangible benefits; user acceptance, higher usability of the product, and a shorter learning curve are just three such benefits. Since clinical processes change only gradually over long periods of time, the cost and effort required to maintain and adapt the software to modifications in the work practice would also be greatly reduced.

6.2 Future Work

We highlight prospective avenues for future work that follow directly from our research:

- Although the NUI software has partially automated arguably the most complex process within CIS, namely the Nursing Process, additional research is needed to address developing computer support for other modules in CIS and integrating them into a larger system. This will involve verifying if the same design methodology used to develop the NUI will work to help provide computer support for the other modules of CIS.
- The repeatability and applicability of the NUI design methodology requires updating the underlying process model by integrating new developments into the

workflow. This needs to be formally tested in a similar or in a related domain that exhibits similar characteristics to healthcare.

- We think that the NUI is maintainable as a standalone module within CIS. This involves easily supporting changes to the system as clinical processes evolve. This needs to be tested through rigorous verification.
- The combination of XP and PD resulted in a good design methodology for healthcare environments with unclear and constantly changing requirements. In spite of this success, future work needs to investigate if there are other combinations of existing design practices that can result in a design process that is equally effective.
- The cost of practicing this approach by industrial software developers also needs to be assessed. Along the same lines, it remains to be researched how one can optimally combine, in industrial software development, the two aspects of generality (wider sales potential) and specific fine tuning to support the nuances of CIS in a particular institution.

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Appendix A

An Ethnographic Study of Organ Transplant Care

Ethnography is a broad topic. As a result, it is conceived in many different ways and several definitions have been proposed [111]. For the purposes of our research, we apply a narrow definition of ethnography: “a descriptive account of social life and culture in a particular social system based on detailed observations of what people actually do” [112]. It then follows that an ethnographic study is the immersion in this social setting to obtain a qualitative understanding of human phenomena. In fact, the process was first developed by anthropologists to better understand social mechanisms by revealing information about the structure, organization and practices of these societies [98]. Today, however, it is commonly being used to help derive requirements for the development of computer systems [98–100].

Our ethnographic study of the organ transplant ward at a large metropolitan hospital took place from February 2nd to March 14th 2004 with the permission of hospital administrators and through the help of coordinators and volunteers. During this six-week study, we examined the activities of five different healthcare professionals; namely: three nurses, a unit coordinator, a head nurse, a pharmacist and a set of physicians during their rounds. Although many different ethnographic techniques have been proposed [100], we applied a straightforward approach whereby, in each case, we selected a willing volunteer and “shadowed” them for their entire work shift. By shadowing our volunteers, we accompanied them as they performed their work tasks and took detailed notes of the

activities they performed and the events that occurred in doing their work. In doing so, we took special attention towards the order of actions and relative time spent on different tasks. A key characteristic of our ethnographic study is that we did not use any knowledge to make pre-suppositions about the work practice. Rather than attempting to impose any of our values, we merely observed and noted details of their practice.

Due to restrictions based on work schedule and availability, it took us six weeks before we were able to complete the ethnographic study of our five healthcare professionals. Throughout the study, our volunteers were extremely accommodating and allowed us to interrupt their work if we were unable to understand exactly what activity they were performing. In the end, we had a detailed account of the activities of the major actors in the ward that we could use to help develop models for computer support.

Appendix B

NUI Software Artifacts

Through our development of the NUI software system, we produced four software artifacts. The first artifact we produced were the models process we developed as a result of our ethnographic study of the organ transplant ward. We discussed these models in detail in Chapter 3. The second artifact we produced (that was refined throughout the design process) was the set of software requirements used to help develop the NUI. This set of software requirements are given below. The third artifact we produced was the NUI database schema. This artifact is important if we wish that the NUI can eventually interoperate with other modules of CIS. The details of the NUI database schema are also given below. Finally, the last software artifact we produced was the NUI user's manual. As we discussed in Chapter 5, this artifact played an important role during our field-test of the NUI software.

NUI Software Requirements

- The NUI shall allow every nurse on-duty to access the patients assigned to their care.
- The NUI shall allow access to PCA's currently on-duty.
- The NUI shall provide password login authentication for all users (nurses, PCAs, head nurse)
- The NUI shall allow authenticated users to change their login credentials.
- The NUI shall allow nurses to assign their patients to another nurse on-duty when they go on break. All data entries made by the substituting nurse shall be marked under their name for accountability purposes.

- The NUI shall provide a mechanism for users to logout of the system.
- Following successful login by a PCA, the NUI shall allow (individual or batch) entry of weight measurements and urine volumes for any ward patient.
- Following successful login by a nurse, the NUI shall allow nurses to navigate between the patient records of their assigned patients at any time without having to logout of the system.
- At all times, the NUI shall display the full name and location (i.e. room number and bed number) for all patients assigned to this nurse.
- The NUI shall mark all data entry and changes to a patient record by the user (nurse, PCA, head nurse) responsible for those changes.
- The NUI shall automate the process of specifying calendar dates to reduce memory load.
- The NUI shall allow zooming to view and edit large blocks of text.
- The NUI shall display to nurses the following patient demographic and state information on an *Overview Panel* in a read-only format:
 - Age
 - Sex
 - Physician's name
 - Allergies
 - Particulars
 - Diagnosis
 - Interventions
 - Nutrition
 - Activity level
 - Vital signs frequency
 - Oxygen saturation
 - Current drains (type)
 - Current IV's (name, rate, access)
 - Daily treatment schedule (date, time, treatment)
- The NUI shall update the *Overview Panel* whenever any underlying information changes.

- The NUI shall allow nurses to record, view, and edit the following information for any assigned patient:

Diagnosis

- Diagnosis
- Interventions

General

- Age
- Physician
- Next of kin
- Allergies
- Particulars

Elimination

- Independent
- Urinal
- Bedpan
- Bathroom with help
- Incontinence care
- Urethra catheter / condom
- Strict input/output
- Peritoneal analysis
- Nephrostomy tube

Respiration

- Humidifier
- CPAP nasal
- Tracheo. care
- Incentive spirometry
- O2 Sat (nasal prongs, mask)

Ambulation

- Activity as tolerated
- Bed rest
- Turning and positioning
- TED stockings
- Restraints
- Traction

Personal Care

- Autonomous
- Partial
- Complete bed
- Mouth care
- Preventative skin care

- The NUI shall allow nurses to record vital signs (individually or via batch entry) for any assigned patient. This information shall include:
 - Vital Sign
 - Blood pressure (posture: sitting, standing, lying)
 - Heart rate (posture: sitting, standing, lying)
 - Temperature
 - Respiratory rate
 - Oxygen saturation
 - Pain level (0-10)
 - Date
 - Time

- The NUI shall allow nurses to view and edit vital signs data (on a daily basis over the past seven days) for any assigned patient.

- The NUI shall (allow nurses to) plot a weekly report of individual data points for each vital sign for any assigned patient. The same data shall also be made available in a tabular format.

- The NUI shall allow nurses to produce a “printer-friendly” version of an assigned patient’s vital signs that replicates (as close as possible) the format of the *Clinical Signs Sheet*.

- The NUI shall allow nurses to record, view and edit the following intake data for any assigned patient:

Nutrition

- Diet
- Fluid restriction
- Enteral feeding

IV Therapies

- Name
- Rate
- Access
- Start date
- Site rotation date
- Tubing change date

- The NUI shall allow nurses to record fluid intake volume measurements for any assigned patient. This information shall include:
 - Intake Source
 - Po
 - Feeding
 - IV solution

- Start level
 - Stop level
 - Absorbed
 - Date
 - Time
- The NUI shall allow nurses to record fluid output volume measurements for any assigned patient. This information shall include:
 - Output Source
 - NG tube
 - Foley catheter
 - Urine
 - Drains 1 & 2
 - Nephrostomy tube
 - Jackson pratt 1& 2
 - Vomit
 - Other
 - Quantity
 - Date
 - Time
- The NUI shall compute and (allow nurses to) plot, on a daily basis over the past seven days, a patient's daily fluid intake volume report for any assigned patient based on three standardized nurse work shifts (7:30-15:29, 15:30-23:29, 23:30-7:29). The same data shall also be made available in a tabular format.
 - The NUI shall compute and (allow nurses to) plot, on a daily basis over the past seven days, a patient's daily fluid output volume report (for all specified output sources) for any assigned patient based on three standardized nursing work shifts (7:30-15:29, 15:30-23:29, 23:30-7:29). The same data shall also be made available in a tabular format.
 - The NUI shall compute and (allow nurses to) plot, on a daily basis over the past seven days, the difference between a patient's 24-hour fluid intake volume and their 24-hour fluid output volume for any assigned patient. The same data shall also be made available in a tabular format.
 - The NUI shall allow nurses to produce a "printer-friendly" version of an assigned patient's fluid intake/output volume that replicates (as close as possible) the format of the *Intake and Output Sheet*.

- The NUI shall allow nurses to add, edit, and view treatments for assigned patients. The treatment details shall include:
 - Date
 - Frequency and first occurrence **OR** Specific daily timings
 - Treatment information

- The NUI shall provide nurses a “reminder service” for daily patient treatments. This “reminder service” shall compute all future treatments times based on the defined treatment specification.

- The NUI shall allow nurses to record, view, and edit the following consult information for any assigned patient:

Consults

- Type
 - Consult
 - Imaging
 - Other
- Date
- Date done
- Consult information

Diagnostic Procedures

- Specimen
 - Stool o.b.
 - Urine c&s
 - Blood c&s
 - Sputum c&s
 - Stool c&s
 - 24-hour urine collection
 - Wound culture
 - Stool c. difficile
 - VRE swab
 - MRSA swab
 - Other
- Date
- Date done

- The NUI shall allow nurses to add medications for any assigned patient. These medication details shall include:
 - Medication name
 - Dosage (10 different units)
 - Frequency (37 different frequencies)
 - Route (16 different routes)

- Administration time
 - Prescribing physician
 - Start date
 - Stop date
- The NUI shall allow nurses to discontinue any medications for an assigned patient.
 - The NUI shall allow nurses to view a complete listing of all active and inactive medications (sorted by start date) for any assigned patient.
 - The NUI shall allow nurses to produce a “printer-friendly” version of an assigned patient’s medication list that replicates (as close as possible) the format of the *Medication Kardex*.
 - The NUI shall allow nurses to record, view, and edit (on daily basis over the past seven days) when an active medication was administered to an assigned patient. This administration information shall include:
 - Medication name
 - Daily dose number
 - Dosage
 - Time
 - The NUI shall allow nurses to produce a “printer-friendly” version of an assigned patient’s medication record that replicates (as close as possible) the format of the *Medication Record*.
 - The NUI shall allow nurses to record glucose level measurements for any assigned patient. This information shall include:
 - Glucose level
 - Date
 - Time of day (ac-breakfast, ac-lunch, ac-supper, ac-bedtime, other)
 - The NUI shall (allow nurses to) plot a weekly glucose report of glucose level readings for assigned patients. The same data shall also be made available in a tabular format.
 - The NUI shall separately display glucose level measurements on the current date for all patients.

- The NUI shall allow nurses to add and remove the following insulin medications for any assigned patient:

Insulin Medications

- HumR
 - HumN
 - Humalog
 - Novolin Toronto
 - Novolin NPH
 - Novorapod
- The NUI shall allow nurses to specify and edit the specification of baseline doses for any insulin medication on the record of any assigned patient.
 - The NUI shall allow nurses to specify and edit the specification of adjusting doses for any insulin medication on the record for any assigned patient.
 - The NUI shall automatically compute the required dosage for any insulin medication based on the baseline dose and the specification for adjusting doses.
 - The NUI shall allow nurses to produce a “printer-friendly” version of a patient’s diabetes medication record for assigned patients that replicate (as close as possible) the format of the *Diabetes Medication Record*.
 - The NUI shall allow nurses to record, edit, and view (over the past seven days) when an insulin or a diabetes medication was administered to an assigned patients. This administration information shall include:
 - Insulin/Diabetes medication name
 - Dosage
 - Time
 - The NUI shall allow nurses to record, edit, and plot daily weights for any assigned patient.
 - The NUI shall allow nurses to view the complete historical set of documented progress notes for any assigned patient.
 - The NUI shall allow nurses to record and timestamp progress notes for any assigned patient.
 - The NUI shall allow nurses to produce a “printer-friendly” version of an assigned patient’s progress notes that replicates (as close as possible) the format of the *Progress Sheet*.

The NUI Database Schema

Relation Name (attribute1, attribute2, ...)
Admin (id, username, password);
Ambulation (id, patientId, activityAsTol, bedRest, turnAndPos, tedStockings, restraints, traction); FOREIGN KEY (patientId) REFERENCES Patient(id)
Consultations (id, patientId, consult, date, dateDone); FOREIGN KEY (patientId) REFERENCES Patient(id)
Daily_Report (id, patientId, date, note); FOREIGN KEY (patientId) REFERENCES Patient(id)
Diagnosis (id, patientId, diagnosis); FOREIGN KEY (patientId) REFERENCES Patient(id)
Elimination (id, patientId, independent, urinal, bedpan, bathroomWH, incontinenceCare, urethCath, strictIO, peritonealDial, nephTube, stoma); FOREIGN KEY (patientId) REFERENCES Patient(id)
Fluid_Intake (id, reported, intakeSource, StartLevel, stopLevel, absorbed, time, modifiedBy, ivType); FOREIGN KEY (reportId) REFERENCES Daily_Report (id)
Fluid_Output (id, reported, outputSource, quantity, time, modifiedBy); FOREIGN KEY (reportId) REFERENCES Daily_Report (id)
Fluid_Output_Sources (id, patientId, ngTube, ngTubeFreq, foleyCath, foleyCathFreq, urine, urineFreq, drain1, drain1Freq, drain2, drain2Freq, nephTube, nephTubeFreq, jpl1, jpl1Freq, jp2, jp2Freq, vomit, vomitFreq, source1Name, source2Name, source3Name, source4Name, source5Name); FOREIGN KEY (patientId) REFERENCES Patient(id)
General (id, patientId, age, physician, nextOfKin, allergies, particulars); FOREIGN KEY (patientId) REFERENCES Patient(id)
Glucose_Record (id, reportId, occurrence, glucoseLevel, time, modifiedBy); FOREIGN KEY (reportId) REFERENCES Daily_Report(id)
Insulin_Meds_Base (id, patientId, insulinMedName, dose1, dose2, dose3, dose4); FOREIGN KEY (patientId) REFERENCES Patient(id)
Insulin_Meds_Scale (id, patientId, insulinMedName, range, dose1, dose2, dose3, dose4); FOREIGN KEY (patientId) REFERENCES Patient(id)
Insulin_Meds_Time (id, patientId, dose1Time, dose2Time, dose3Time, dose4Time); FOREIGN KEY (patientId) REFERENCES Patient(id)
Insulin_Record (id, reportId, insulinMed, doseNumber, dose, time, modifiedBy); FOREIGN KEY (reportId) REFERENCES Daily_Report(id)
Interventions (id, patientId, intervention, interventionDate); FOREIGN KEY (patientId) REFERENCES Patient(id)
Iv (id, patientId, iv, rate, startDate, rotationDate, changeDate, access); FOREIGN KEY (PatientId) REFERENCES Patient(id)
Med_Record (id, reportId, medName, dose, time, modifiedBy); FOREIGN KEY (reportId) REFERENCES Daily_Report(id)
Medications (id, patientId, medName, dose, medicationUnits, frequency,

route, adminTimes, physician, startDate, stopDate, diabetesMed, medStatus); FOREIGN KEY (patientId) REFERENCES Patient(id)
Nurse (id, firstName, lastName, password, breakStatus, assignedTo);
Nutrition (id, patientId, diet, specialOtherDiet, fluidRestriction, fluidRestrictionValue, enteralFeeding); FOREIGN KEY (patientId) REFERENCES Patient(id)
Other_Consultations (id, patientId, otherConsult, date, dateDone); FOREIGN KEY (patientId) REFERENCES Patient(id)
Patient (id, firstName, lastName, cause, medicareNum, patientNum, gender);
Patient_Nurse (nurseId, patientId, transferNurseId); FOREIGN KEY (nurseId) REFERENCES Nurse(id) FOREIGN KEY (patientId) REFERENCES Patient(id)
Patient_Room (roomNum, patientId, bedNum); FOREIGN KEY (patientId) REFERENCES Patient(id)
Pca (id, firstName, lastName, password);
Personal_Care (id, patientId, autonomous, partialCare, completeBed, mouthCareAM, mouthCareQH, mouthCareValue, skinCare); FOREIGN KEY (patientId) REFERENCES Patient(id)
Progress_Notes (id, reportId, progressNotes, time); FOREIGN KEY (reportId) REFERENCES Daily_Report(id)
Respiration (id, patientId, humidifier, cpapNasal, tracheoCare, incentiveSpiro, nasalProngs, nasalMask); FOREIGN KEY (patientId) REFERENCES Patient(id)
Specimens (id, patientId, specimen, date, dateDone); FOREIGN KEY (patientId) REFERENCES Patient(id)
Treatments (id, patientId, date, frequency, firstOccurrence, computedTimes, treatment, nextDayDue); FOREIGN KEY (patientId) REFERENCES Patient(id)
Vitals (id, reported, bloodPressurePosture, bloodPressure, heartRatePosture, heartRate, temperature, respiratoryRate, oxygenSatType, oxygenSat, maskProngsValue, painLevel, time, modifiedBy); FOREIGN KEY (reportId) REFERENCES Daily_Report(id)
Vitals_Frequency (id, patientId, vitalSigns, oxygenSat, neuroSigns); FOREIGN KEY (patientId) REFERENCES Patient(id)
Weight (id, reportId, weight, modifiedBy); FOREIGN KEY (reportId) REFERENCES Daily_Report(id)
Xrays (id, patientId, xRay, date, dateDone); FOREIGN KEY (patientId) REFERENCES Patient(id)

Table B.1 – NUI database schema

Appendix C

The NUI Versus the Paper-Based Process

Current (Paper-Based) Process	Nurse User Interface (NUI)
<ol style="list-style-type: none"> 1. Nurse starts shift 2. Nurse checks patient assignment 3. Nurse checks nursing notes from <i>Progress Sheet</i> and patient tasks from the patient's <i>Nursing Kardex Sheet</i>. 	<ol style="list-style-type: none"> 1. Nurse logs into NUI 2. Patient assignment is visible in NUI 3. Nurse views notes on <i>Progress Notes Panel</i> and a snapshot of the current state/tasks of the patient from the <i>Overview Panel</i>
<ol style="list-style-type: none"> 4. Nurse – Direct Patient Care <ol style="list-style-type: none"> 4.1 Information Collection <ol style="list-style-type: none"> 4.1.a Patient demographic information on <i>Health Assessment Module Sheet</i> and <i>Patient and Family Database Sheet</i> and the patient's <i>Nursing Kardex Sheet</i> 4.1.b Patient vitals signs on <i>Clinical Signs Sheet</i>. Data points are plotted manually. 4.1.c Patient intake and output on <i>Intake & Output Sheet</i>. Total volumes are computed manually at the end of each 8-hour shift. 4.1.d Glucose levels on <i>Diabetes Medication Record Sheet</i>. Data points are not graphed. 4.2 Administration of Treatments <ol style="list-style-type: none"> 4.2.a Nurse administers: General Treatments. Consult the patient's <i>Nursing Kardex Sheet</i>. 4.2.b Nurse administers: Medications. Consult <i>Medication Kardex Sheet</i>, record details and sign <i>Medication Record Sheet</i>. 4.2.c Nurse administers: Insulin. Consult <i>Orders for Insulin Therapy Sheet</i>, record details and sign <i>Diabetes Medication Record Sheet</i>. 	<ol style="list-style-type: none"> 4. Nurse – Direct Patient Care <ol style="list-style-type: none"> 4.1 Information Collection <ol style="list-style-type: none"> 4.1.a Patient demographic information on <i>General Panel</i> 4.1.b Patients vitals on <i>Vitals Panel</i> in NUI. Data points are plotted automatically. 4.1.c Patient intake and output on <i>Intake & Output Panel</i> in NUI. Total volumes are computed automatically at the end of each 8-hour shift. 4.1.d Glucose levels on <i>Glucose Panel</i> in NUI. Data points are graphed automatically. 4.2 Administration of Treatments <ol style="list-style-type: none"> 4.2.a Nurse administers: General Treatments. Consult <i>Treatments and Consults Panel</i> in NUI. 4.2.b Nurse administers: Medication. Consult and record on <i>Medication Panel</i> in NUI. 4.2.c Nurse administers: Insulin. Consult and record details on <i>Glucose Panel</i> in NUI. Required dosage is automatically computed by

<p>Required dosage is manually computed based on glucose levels. 4.2.d Nurse administers: IV Therapy. Record details on <i>Intake & Output Sheet</i> and patient's <i>Nursing Kardex Sheet</i>.</p> <p>5. Nurse – Indirect Patient Care 5.1 Charting 5.1.a. Progress Notes on <i>Progress Sheet</i> 5.1.b. Information Update. Nurse reviews patient's <i>Nursing Kardex</i>, collects required sheets, and updates necessary information.</p> <p>5.2 Nurse follow-up for Consults, Treatments and Physician orders 5.2.a. Physician orders: Treatments. Written on patient's <i>Nursing Kardex Sheet</i> organized by date.</p> <p>5.2.b. Physician orders: Consults. Written on patient's <i>Nursing Kardex Sheet</i> organized by date.</p> <p>5.2.c. Physician orders: Medications. Written on <i>Medication Kardex Sheet</i> or verbal order.</p>	<p>system based on the current glucose levels. 4.2.d Nurse administers: IV Therapy. Record details on <i>Intake & Output Panel</i> in NUI.</p> <p>5. Nurse – Indirect Patient Care 5.1 Charting 5.1.a. Progress notes on <i>Progress Notes Panel</i> in NUI 5.1.b. Information Update. Nurse reviews <i>Overview Panel</i> and updates any other necessary Panels.</p> <p>5.2 Nurse follow-up for Consults, Treatments and Physician orders 5.2.a. Physician orders: Treatments. Viewable and traceable on <i>Treatments & Consults Panel</i> in NUI. Proactive alert organizes treatments by date relevancy. 5.2.b. Physician orders: Consults. Viewable and traceable on <i>Treatments & Consults Panel</i> in NUI. Proactive alert monitors the status of the consult 5.2.c Physician orders: Medications. Viewable from <i>Medications Panel</i> in NUI</p>
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Table C.1 – The NUI vs. the paper-based process

Appendix D

Paper-Based Forms of the Organ Transplant Ward

1. The Nursing Kardex

Patient Information		Diagnosis		Nursing Interventions		Medications		Diet		Activity		Vital Signs		Instruments		Special Diets		Special Treatments		Special Procedures		Special Tests	
Name	Room No.	Diagnosis 1	Diagnosis 2	Intervention 1	Intervention 2	Medication 1	Medication 2	Diet Type	Activity Level	Vital Signs	Instruments	Special Diet	Special Treatment	Special Procedure	Special Test	Special Test	Special Test	Special Test	Special Test	Special Test	Special Test	Special Test	Special Test
<p>ASSESSMENT</p> <p>1. Cardiovascular: Monitor vital signs, assess for edema, monitor intake/output.</p> <p>2. Respiratory: Monitor respiratory rate, auscultate lung sounds, administer oxygen as ordered.</p> <p>3. Neurological: Monitor level of consciousness, assess for focal deficits.</p> <p>4. Renal: Monitor urine output, assess for fluid balance.</p> <p>5. Endocrine: Monitor blood glucose levels, administer insulin as ordered.</p> <p>6. Integumentary: Monitor skin integrity, assess for pressure ulcers.</p> <p>7. Psychosocial: Provide emotional support, assess for anxiety.</p>																							
<p>PLAN</p> <p>1. Maintain stable vital signs.</p> <p>2. Ensure adequate oxygenation.</p> <p>3. Monitor and report changes in neuro status.</p> <p>4. Maintain fluid balance.</p> <p>5. Maintain blood glucose within target range.</p> <p>6. Prevent skin breakdown.</p> <p>7. Provide patient education.</p>																							
<p>IMPLEMENTATION</p> <p>1. Administer medications on schedule.</p> <p>2. Perform vital signs every 4 hours.</p> <p>3. Monitor intake/output hourly.</p> <p>4. Administer oxygen at 2 L/min via nasal cannula.</p> <p>5. Monitor blood glucose every 4 hours.</p> <p>6. Turn patient every 2 hours.</p> <p>7. Provide patient education regarding diet and activity.</p>																							
<p>EVALUATION</p> <p>1. Patient's vital signs are stable.</p> <p>2. Patient is breathing comfortably.</p> <p>3. Patient's level of consciousness is alert.</p> <p>4. Patient's urine output is adequate.</p> <p>5. Patient's blood glucose levels are within target range.</p> <p>6. Patient's skin is intact.</p> <p>7. Patient is understanding instructions.</p>																							
<p>PROBLEMS/TREATMENTS</p> <p>1. Problem: Risk for infection. Treatment: Administer antibiotics as ordered.</p> <p>2. Problem: Risk for fluid volume excess. Treatment: Monitor intake/output, administer diuretics as ordered.</p> <p>3. Problem: Risk for hypoglycemia. Treatment: Monitor blood glucose, administer glucose as ordered.</p>																							
<p>DIAGNOSTIC PROCEDURES</p> <p>1. Procedure: Chest X-ray. Date: []/ []/ [].</p> <p>2. Procedure: Urinalysis. Date: []/ []/ [].</p> <p>3. Procedure: Blood glucose. Date: []/ []/ [].</p>																							
<p>CONSULTATIONS</p> <p>1. Consultant: Dietitian. Date: []/ []/ [].</p> <p>2. Consultant: Physical Therapist. Date: []/ []/ [].</p>																							
<p>EXAMINATIONS</p> <p>1. Exam: Physical. Date: []/ []/ [].</p> <p>2. Exam: ECG. Date: []/ []/ [].</p>																							
<p>RESEARCH/INVESTIGATIONS/THERAPY</p> <p>1. Study: IV. Date: []/ []/ [].</p> <p>2. Study: Dialysis. Date: []/ []/ [].</p>																							
<p>DIAGNOSIS/CO-DIAGNOSIS</p> <p>1. Diagnosis: Acute Kidney Injury.</p> <p>2. Diagnosis: Hypertension.</p> <p>3. Diagnosis: Diabetes Mellitus.</p>																							
<p>POINTS</p> <p>1. Point: Allergy. Value: 1.</p> <p>2. Point: Infection. Value: 2.</p> <p>3. Point: Fluid Balance. Value: 3.</p> <p>4. Point: Blood Glucose. Value: 4.</p> <p>5. Point: Skin Integrity. Value: 5.</p> <p>6. Point: Patient Education. Value: 6.</p>																							
<p>TOTAL</p> <p>1. Total: 21.</p>																							

Figure D.1 – The nursing kardex

2. The Clinical Signs Sheet

RAPPORT DES SIGNES VITAUX ET DOSAGES
CLINICAL SIGNS SHEET

MOIS ET ANNÉE
MONTH & YEAR

	JOUR DAY																																			
	HEURES HOURS																																			
	4	8	12	16	20	24	4	8	12	16	20	24	4	8	12	16	20	24	4	8	12	16	20	24	4	8	12	16	20	24	4	8	12	16	20	24
TEMPERATURE	C° 40°																									40°										
	39°																									39°										
	38°																									38°										
	37°																									37°										
	36°																									36°										
DOULEUR PAIN	5																									5										
	4																									4										
	3																									3										
	2																									2										
	1																									1										
	0																									0										
TENSION ARTÉRIELLE/ BLOOD PRESSURE	180																									180										
	160																									160										
	140																									140										
	120																									120										
	100																									100										
	80																									80										
	60																									60										
	20																									20										
RESPIRATION	50																									50										
	40																									40										
	30																									30										
	20																									20										
	10																									10										
DÉFÉCATION STOOLS																																				
POIDS WEIGHT																																				
JOUR P.O. DAY PGST-OP.																																				

INTENSITÉ DE LA DOULEUR PAIN SCALE
 0 PAS DE DOULEUR NO PAIN
 1 LÉGÈRE MILD
 2 GÉNANT DISCOMFORTING
 3 PÉNIBLE DISTRESSING
 4 SÉVÈRE HORRIBLE
 5 INSUPPORTABLE EXCRUCIATING

Figure D.2 – The clinical signs sheet

3. The Intake and Output Sheet

**BILAN INGESTA ET EXCRETA
INTAKE & OUTPUT SHEET**

DATE: _____
 SOLUTÉ SEULEMENT / IV ONLY:
 RESTRICTION LIQUIDIENNE / FLUID RESTRICTION: _____ 24 hrs
 N/L = Niveau / Level

INGESTA / INTAKE						EXCRETA / OUTPUT			
HEURE TIME	PO	GAVAGE FEEDING	SOLUTÉ I.V. IV SOLUTION	NIVEAU LEVEL	ABSORBÉ ABSORBED	URINE	N / L	N / L	
7h30									
15h30									
8hr Sous/Sub Total									
8hr TOTAL INGESTA / INTAKE: _____						8hr TOTAL EXCRETA / OUTPUT: _____			
15h30						URINE	N / L	N / L	
23h30									
8hr Sous/Sub Total									
8hr TOTAL INGESTA / INTAKE: _____						8hr TOTAL EXCRETA / OUTPUT: _____			
23h30						URINE	N / L	N / L	
7h30									
8hr Sous/Sub Total									
8hr TOTAL INGESTA / INTAKE: _____						8hr TOTAL EXCRETA / OUTPUT: _____			
24hr TOTAL									
TOTAL INGESTA / INTAKE: _____						TOTAL EXCRETA / OUTPUT: _____			

Figure D.3 – The intake and output sheet

4. The Medication Kardex

REGISTRE DES MÉDICATIONS MEDICATION KARDEX					
RELEVÉ PAR – TRANSCRIBED BY		VÉRIFIÉ PAR – CHECKED BY			
OBSERVATIONS SPÉCIALES – SPECIAL CONSIDERATIONS					
D.I. I.D.	D.F. F.D.	MÉDICATIONS PERMANENTES STANDING MEDICATIONS	HEURE D'ADMINISTRATION TIME TO BE GIVEN		
			7h30 - 15h30	15h30 - 23h30	23h30 - 7h30
		Prograf		20	7 ³⁰
		Tromebin	12	18	00 6
		Gamylolair	10	22	
		Allystabin	8 12	18 22	
			8	17 22	7
D.I. I.D.	D.F. F.D.	MÉDICATIONS AU BESOIN PRN. MEDICATIONS	HEURE D'ADMINISTRATION TIME TO BE GIVEN		

ALLERGIES (UTILISER RUBAN D'ALLERGIE ROUGE ET BLANC)
ALLERGIES (USE RED & WHITE ALLERGY TAPE)

Figure D.4 – The medication kardex

6. Orders for SC Insulin Therapy

**PRESCRIPTION POUR L'INSULINE SC
ORDERS FOR SC INSULIN THERAPY**

Date: _____ Heure/hour: _____

DOSE DE BASE / 'BASELINE' DOSE:

MARQUE D'INSULINE BRAND OF INSULIN	AC-breakfast Avant déjeuner ou/or _____ hr	AC-lunch Avant dîner ou/or _____ hr	AC-supper Avant souper ou/or _____ hr	HS Au coucher ou/or _____ hr

**AJUSTEZ LA DOSE SELON L'ÉCHELLE SUIVANTE AUX HEURES INDICUÉES:
(+ = AUGMENTEZ LA DOSE, -- = DIMINUEZ LA DOSE, Δ = PAS DE CHANGEMENT)
ADJUST DOSE ACCORDING TO FOLLOWING SCALE AT INDICATED TIMES:
(+ = INCREASE DOSE, -- = DECREASE DOSE, Δ = NO CHANGE)**

	Avant déjeuner AC-breakfast ou/or _____ hr	Avant dîner AC-lunch ou/or _____ hr	Avant souper AC-supper ou/or _____ hr	Au coucher HS ou/or _____ hr
MARQUE D'INSULINE A AJUSTER BRAND OF INSULIN TO ADJUST				
GLYCÉMIE CAPILLAIRE CAPILLARY GLUCOSE	0.0 - 4.0 mmol/L**			
	4.1 - 6.0			
	6.1 - 8.0			
	8.1 - 10			
	10.1 - 12			
	12.1 - 14			
	14.1 - 16			
	16.1 - 18			
> 18 (Informez/notify MD)				

[**Traiter l'hypoglycémie d'abord, pour atteindre un glucose > 6, puis donner la dose d'insuline telle que prescrite pour les niveaux de 0.0-4.0 mmol/L. / Treat hypoglycemia first to get glucose > 6, then give dose of insulin ordered for 0-4.0 mmol/L range.]

SIGNATURES:
 Consulting Service: _____ Date: _____ Time: _____
 Service/Signature/Name Printed/License No. _____
 Primary Service: _____ Date/Time: _____ Nurse: _____ Date/Time: _____

Figure D.6 – Orders for sc insulin therapy

7. The Diabetes Medication Record

**RELEVÉ DES MEDICAMENTS POUR LE DIABETE
DIABETES MEDICATION RECORD**

AC
PC

DATE	MEDICATION	HEURES - HOURS				GLUCOSE				REACTION
		AM	MIDI	PM	HS	AM	MIDI	PM	HS	
						GLUCOSE METER				
						GLUCOSE LAB				
						KETONE - URINE				
NPO Diet:						GLUCOSE METER				
DATE						GLUCOSE LAB				
NPO Diet:						KETONE - URINE				
DATE						GLUCOSE METER				
						GLUCOSE LAB				
NPO Diet:						KETONE - URINE				
DATE						GLUCOSE METER				
						GLUCOSE LAB				
NPO Diet:						KETONE - URINE				
DATE						GLUCOSE METER				
						GLUCOSE LAB				
NPO Diet:						KETONE - URINE				

SIGNATURE DU RESPONSABLE
SIGNATURE KEY

Figure D.7 – The diabetes medication record

8. The Progress Sheet

NOTES D'EVOLUTION PROGRESS SHEET		
SERVICE	A/Y / M / J/D HRES/HRS	NOTES

Figure D.8– The progress sheet