ABSTRACT

Title: APPROPRIATING VALUE FROM INFORMATION TECHNOLOGY IN HEALTHCARE

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Decision, Operations & Information Technologies

The value potential of information technology (IT) in healthcare settings has generated considerable optimism yet, significant questions remain unanswered. This dissertation employs the lens of social structure to investigate the value of information technology in healthcare situated in two distinct contexts: hospitals, that exemplify the traditional institutional form for the delivery of healthcare services, and online health communities that represent new organizational forms enabled by IT. It seeks to address the following fundamental research questions “What is the impact of information technology in healthcare settings? How does social structure influence the appropriation of the value of information technology in healthcare?” Each of the two contexts is investigated in a separate essay, drawing upon distinct bodies of literature and using both qualitative and quantitative analytical methods.

Essay 1: Evolving Work Routines: Adaptive Routinization of Information Technology in Healthcare

The first essay investigates the impact of healthcare technologies such as electronic medical record systems in the traditional hospital environment. It traces the development of changes in social structure before and after an IT implementation. Using a longitudinal field study, the process of how information technology and routines interact is deconstructed. A theory of the co-evolution of routines and technology is proposed and described.

Essay 2: The Social Value of Online Health Communities

The second essay examines the impact of health information technology in the form of online health communities by uncovering the social structure of the community. Using data collected from a popular online health community, I identify the generative processes using support patterns between patients within the community. I find that online health communities yield social value through informational and emotional support to patients by enabling the transfer of support between patients with differential needs. Results also provide descriptive insights into the attributes of patients that contribute to variation in the provision of support within such online health communities.

The two studies in this dissertation make theoretical and empirical contributions. They shed light on the impact of information technology in healthcare, and further inform us about the appropriation of value of HIT from a social structure perspective.

APPROPRIATING VALUE FROM INFORMATION TECHNOLOGY IN HEALTHCARE

By

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Overview

There is optimism today about the role that information technology (IT) can play in addressing some of the core deficiencies that confront healthcare. Policy makers and healthcare executives argue that health IT offers the potential of yielding benefits such as improved healthcare quality, reduced costs and increased efficiency by enhancing information flows and closing information gaps. Despite these claims, however there is still limited evidence demonstrating the value derived from implementing information technology in healthcare settings. Arguably, this has been a key constraining factor impeding broad-based penetration of health IT. Indeed, studies seeking to understand the slow uptake of IT in healthcare consistently point to a key concern among non-adopters that the payoffs from their investment are unclear (Agarwal et al., 2010; Jha et al., 2009; DesRoches et al., 2008). Several important questions remain unanswered: What is the value of information technology in healthcare? How can this value be realized and appropriated?

Answering these questions in order to understand how we can harness the value of information technology is, unsurprisingly, a significant challenge. It requires a deep understanding of the underlying workings of health information technology and the complexities of the healthcare industry. This dissertation employs a social structure lens to uncover these complexities in two contexts in healthcare in which information technology has a potential to generate considerable benefit: hospitals (i.e. in the traditional context) and the Internet (i.e. in the Web 2.0 context). Social structure, which refers to the enduring ensemble of relationships among actors, abounds in both hospitals and online health communities. In hospitals, the implementation of IT affects and modifies existing social structures in the form of organizational routines. In online health communities, social structure emerges in the form of networks of connections enabled by IT. Social structure can both constrain and enable the value of IT and is highly salient to the realization of the potential of health IT. Therefore, using a theoretical and analytical lens grounded in social structure will help to advance our understanding of the impact of health IT.

The two essays comprising this dissertation examine the impact of two different forms of information technology in healthcare by focusing on the social structure created and modified by the IT. The dissertation seeks to address two fundamental research questions: "What is the impact of information technology in healthcare settings? How does social structure influence the appropriation of the value of information technology in healthcare?"

The first essay in this dissertation investigates information systems implemented in a hospital setting. It examines the mechanisms underlying successful health information technology (HIT) implementations. Drawing upon literature on narrative networks and adaptive structuration theory, a longitudinal field study was conducted in a hospital to gain a deep understanding of the interplay between technology and clinical work routines in this unique and complex setting. Using intensive data analysis methods, the findings from this study suggest that actively managing the co-evolution process between routines and HIT to create a virtuous cycle is key to successful HIT implementations. The study concludes with a theoretical model of adaptive routinization of technology.

The second essay examines the social value of online health communities using a social structure lens. Using data collected from a rare disease forum, the social network structure is analyzed and exponential random graph models of this community are developed. Findings from this study suggest that online health communities provide a platform for urban and rural patients to interact and exchange information about various aspects of the disease: prognosis and nature of disease, treatment, medication, restoration and coping information etc. The findings indicate that the community creates social welfare by bridging the location health divide, i.e., prognosis and nature of disease of information flow from urban to rural patients. Urban patients were also found to provide a substantial level of emotional support to rural patients.

Essay 1: Evolving Work Routines: Adaptive Routinization of Information Technology in Healthcare*

Abstract

Despite the significant potential for performance gains from Health IT (HIT), there has been limited study of the mechanisms underlying successful HIT implementations. We conducted an extensive, longitudinal field study to gain an understanding of the interplay between technology and patterns of clinical work embodied in routines. We use the analytical device of narrative networks to identify where and how HIT influences patterns of work. We further draw upon adaptive structuration theory to conceptualize HIT as an intervention that alters the flow of events in a narrative network. Our findings suggest that the key to successful implementation is to manage the co-evolution process between routines and HIT and to actively orchestrate a virtuous cycle through agentic action. We propose a dynamic, process model of adaptive routinization of HIT that delineates the major channels through which HIT and routines interact, identifies the different stages in the dynamic co-evolution process, and isolates the pivotal role of two forms of agency in enabling the virtuous cycle of co-evolution. This is one of the first studies to offer a processual, micro-level analysis of HIT implementation in a clinical setting.

* An article based on this research and co-authored with Guodong (Gordon) Gao and Ritu Agarwal has been published in the Information Systems Research, September 2011.

1 Introduction

In recent years, key political actors and advocacy groups have argued for an increased use of health IT (HIT) to improve the quality of health care and lower delivery costs (Kohn et al., 2000; Birkmeyer et al., 2000; Hillestad et al., 2005). Despite strong interest and encouragement from the government however, hospitals and physicians are lagging behind in their adoption of HIT (DesRoches et al., 2008; Jha et al., 2009). Among the multiple barriers to HIT adoption that have been identified in previous studies, physicians' concerns about the performance impacts of HIT are frequently implicated as representing one of the most formidable obstacles. In particular, physicians have expressed reservations that HIT systems will not fully meet their needs (DesRoches et al. 2008), or worse, will result in decreased clinical efficiency and effectiveness (Simon et al. 2007). Loss of productivity due to the disruption caused by HIT implementation has led to highly visible failures even in leading healthcare organizations such as Kaiser Permanente (Scott 2005).

Up until now, limited research has been conducted on the mechanisms underlying successful HIT implementation. Rather, studies of IT in healthcare settings have focused on the task of measuring the impact of HIT (e.g., Chaudhry et al. 2006; Amarasingham et al., 2009; Devaraj and Kohli, 2000, 2003; Kohli and Devaraj, 2004). While these papers provide a foundation for quantifying the value of HIT, they do not shed much light on a critical precondition for HIT impact: the vexing issue of what it takes for an HIT system to be effectively implemented. The absence of such an understanding will inevitably constrain the ability of healthcare organizations to fully appropriate value from their IT investments.

In this paper, we seek to unpack the "black box" of HIT implementation in hospitals. A core challenge in accomplishing this is the widely documented fact that the processes of care delivery are exceedingly complex and involve significant coordination, interdependence, and interactions among care providers (Gawande, 2002; Tucker et al., 2007). When HIT intervenes, these processes can be disrupted in unexpected ways (cf. Edmondson et al., 2001). Thus, the success of HIT interventions is significantly influenced by the characteristics of extant work patterns, the micro-social context and the manner in which the process of implementation unfolds (e.g., Lapointe and Rivard, 2007). Failure to incorporate these elements into theoretical explanations may yield conflicting and potentially misleading results.

To address our research objective, we conducted a detailed field study of a HIT implementation in a large hospital. Our field work draws upon the conceptual foundation of organizational routines and is further informed by adaptive structuration theory (AST), and health informatics literature. Routines are the relatively stable action repertoires executed by actors across time and space to accomplish organizational work (Nelson and Winter, 2002; Feldman and Pentland, 2003). In healthcare, routines are at the core of daily operations in hospitals and play a pivotal role in determining efficiency and quality of care (Greenhalgh, 2008). Indeed, in spite of the high level of skill and expertise that is required for successful care delivery, the practice of healthcare is highly routinized, and may prove to be even more so with the emergence of care protocols that detail the specific actions that caregivers must take (Dy et al., 2005). To the degree that HIT must be successfully and rapidly integrated into the daily routines of a hospital in order to realize performance gains, using an organizational routines lens to investigate HIT implementation is particularly appropriate.

Several studies have demonstrated that the introduction of new medical technology can trigger the disruption of routines in healthcare settings (Barley, 1986; Edmondson et al., 2001). However, in contrast to medical technologies such as CT scanners investigated in these studies that primarily change the execution of specific tasks, as an instance of information and communication technology (ICT), HIT has distinctive features that may disrupt routines in unique ways (Pentland and Feldman 2008). In particular, HIT predominantly influences the information flow of routines. In order to gain a more granular understanding of how HIT interacts with routines, we use the analytical device of narrative networks (Pentland and Feldman, 2007) to identify where and how HIT influences information flow. We further draw upon *adaptive structuration theory (AST)* originally described by DeSanctis and Poole (1994) and recently refined and extended by Markus and Silver (2008), to conceptualize HIT as a collection of functional affordances and symbolic expressions that can alter the flow of events in a narrative network. We use insights from the health informatics literature about the distinctive characteristics of the healthcare context in general and hospitals in particular to inform our theorizing and aid in the interpretation of findings.

Drawing on an extensive and rich data set collected using multiple methods, we address the following overarching research questions: How does HIT influence routines in healthcare delivery? What are the key processes and factors that influence successful implementation of information technology in healthcare? Based on our findings, we propose a dynamic, process model of *adaptive routinization of HIT* that explicates the mechanisms through which HIT systems are incorporated into hospital routines, resulting in successful implementation.

This study contributes to and complements the existing literature by identifying the dynamics of change underlying successful HIT implementations. Although the notion of organizational routines and how they interact with technology has been discussed before (e.g., Pentland and Feldman 2008), to the best of our knowledge, this study is among the first to adopt a routine-based perspective to understand the mechanisms responsible for successful HIT implementations for the realization of HIT value. As such, it provides an alternative and useful counterpoint to firm-level studies that focus predominantly on the relationship between HIT investment and outcomes without explicitly exploring the principal causal processes.

2 Theoretical Foundation and Prior Literature

We begin with a brief review of the extant literature addressing the implementation and impact of IT in healthcare settings. We then describe the concept of organizational routines and the analytical tool of narrative networks. We conclude by highlighting the role of agency in steering the narratives associated with a new technology in a value creating direction.

2.1 HIT and health informatics

The clinical literature contains a robust number of studies of HIT impact, as summarized in several recent reviews (Kaushal et al 2003, Chaudhry et al 2006, Golzweig et al 2009). Although these studies provide evidence that HIT improves performance, we note that most of the findings are generated from a few leading institutes by conducting before-after comparisons. To the degree that successful implementation is a precondition for the realization of HIT value, this literature does not inform understanding of the underlying drivers and processes.

Other studies provide evidence suggesting that making HIT work in a clinical setting is a challenging proposition (Scott et al. 2005, Simon et al. 2007, DesRoches et al. 2008). Findings indicate that HIT implementation failures can be attributed primarily to physicians' frustration with the system's functionality and the difficulty that they experienced integrating the technology into their established workflows. There is considerable skepticism among clinicians about both the value that HIT systems offer, and their ability to effectively appropriate this value.

A handful of studies in the IS literature seek to understand the HIT implementation process. LaPointe and Rivard (2005) examined why HIT implementation fail and concluded that in the absence of successful adaptation, a multitude of negative outcomes or “resistance behaviors” can occur which may eventually lead to the abandonment of the technology. In later work, findings show that systems were abandoned due to a myriad of factors including resistance, misalignment of expectations, and disruption to workflow (Davidson and Chiasson 2005, Mogard et al. 2006). Thus, despite variations in settings, theories, and methodological approaches, a dominant conclusion of these studies is that HIT implementation is indeed a complex and difficult task.

The complexity arises in part due to the unique characteristics of the context in which HIT is situated. First, the nature of work in patient care delivery is intrinsically complicated, time-sensitive, and highly uncertain. Ren et al (2008) identify several sources of unexpected interruptions in operating rooms. Nembhard et al. (2009) suggest that the fear of risk and strongly imbued norms such as avoiding patient harm at all costs often contribute to innovation implementation failure. Second, this industry is characterized by a potent professional identity tied to the strongly hierarchical, authoritarian, and autonomous culture of health professionals (Leape and Berwick 2005; Mannion et al. 2009). As such, attending physicians and consulting physicians receive the highest respect from all other healthcare providers in the hospital (Wright et al. 1998), and their authority is seldom challenged. Finally, the specialized nature of the profession and the need for deep knowledge and skills also contributes to the need for a highly collaborative culture for patient safety and high quality of care. This collaboration, involving significant exchange of information, has to be carefully spelled out through protocols to ensure adherence to the highest standards of care delivery. These particular characteristics of the healthcare context suggest the importance of focusing on routines for a comprehensive understanding of successful HIT implementation.

Our review of the literature on HIT value and HIT adoption and implementation yields three broad conclusions. First, although the issue of HIT value has been studied fairly extensively in the health informatics literature, studies in that domain are not theoretically grounded and seek mainly to establish empirical associations; i.e., it is not their core objective to provide an explanation for the mechanisms and drivers underlying the observed effects. Second, physicians have expressed significant concerns about whether HIT can be successfully adapted to their daily workflows without a negative impact on productivity (Niazkhani et al. 2009), which in turn has led to widespread resistance to HIT. Up to this point, a clear understanding of the mechanisms for successful HIT implementation has remained elusive. Chaudhry et al. (2006) reinforce this observation in their conclusion: "the limited quantitative and qualitative description of the implementation context significantly hampers how the literature on health information technology can inform decision making by a broad array of stakeholders interested in this field." The work reported here seeks to address these gaps in the literature.

2.2 Routines and healthcare

We approach the implementation of HIT using the theoretical lens of organizational routines. Routines are regular and repetitive action patterns performed by multiple actors across time and space (Feldman and Pentland 2003). As noted, the importance of routines has been underscored extensively by scholars in multiple fields (for a review, see Becker 2004). Routines are frequently recognized as a key organizational capability (Winter, 2003), and have been shown to influence performance outcomes (Cohen and Bacdayan, 1994; Gittell, 2002).

In hospital settings, clinical routines specify the regular pattern of activities that caregivers must engage in as they administer patient care (e.g. rounding, patient information transfer) (Wright et al., 1998). Indeed, routines are of particular importance in high reliability settings like hospitals because there is little room for error (Weick and Sutcliffe, 2006; Tucker et al., 2007). As such, hospital routines ensure that quality is met through the consistent refinement of standard operating procedures. The release of the influential *Institute of Medicine Reports* (1999) suggesting that quality problems in healthcare were largely an outcome of process variation served to renew the focus on care delivery routines in the industry.

Several influential studies have underscored the disruptions caused by technological innovations in health care settings. Barley (1986, 1990) examined how organizational structures changed with the introduction of CT scanners and radiology imaging devices, respectively. Edmondson et al (2001) investigated how a new cardiac surgery technology disrupted existing routines and how team learning occurred. The disruption caused by new technologies can lead to productivity losses or even a higher level of errors (Embi 2004; Weir 2003). This initial negative performance impact usually fosters the resistance of physicians, and may even result in the abandonment of an HIT implementation effort (Scott et al., 2005). To the extent that identifying and working to manage the resistance from physicians is a key issue in HIT adoption (Jha et al. 2009), studying physician resistance to technology change from the routines perspective could generate important insights pertinent to HIT implementation.

Despite the ubiquity of routines in care delivery processes and the centrality of routines to the fundamental work in hospitals, there is a surprising paucity of rich, in-depth studies of routines in healthcare in the literature (Greenhalgh, 2008). Even less is known about the interactions between HIT and routines during the implementation period; an unanswered question that this study addresses.

2.3 The interaction of technology and routines: Narrative networks, functional affordances, and symbolic expressions

Compared to clinical technologies, HIT possesses unique features that affect routines in distinctive ways, motivating us to utilize narrative networks and AST for in-depth analysis of how HIT interacts with routines. Pentland and Feldman (2007) introduced the narrative network as an analytical tool for mapping the actual and potential patterns of action that occur in an organizational routine. A "narrative" network encapsulates the possible narratives or story lines that surround any organizational activity. Rather than showing relations between actors, each node in a narrative network is a "functional event" or action that moves the story forward. The notion of a narrative network explicitly acknowledges the existence of a plurality of patterns of action that can be associated with the accomplishment of a specific organizational routine.

When technology enters an existing narrative, it brings with it new capabilities that may change "the set of possible stories" (Pentland and Feldman, 2007. To theorize the interactions between technology and narratives, we draw upon adaptive structuration theory (Markus and Silver, 2008), which characterizes technology as a bundle of tangible functional affordances and more ephemeral symbolic expressions. A functional affordance refers to the "type of relationship between a technical object and a specified user that identifies what the user may be able to do with the object, given the user's capabilities and goals" (Markus & Silver 2008, p. 622). Simply put, a technology's functional affordances (what the user can do with the technology) expand (or limit) the range of paths along which a narrative can unfold. The concept of symbolic expressions is used to capture the values orientation of the technology, i.e., the "communicative possibilities of a technical object for a specified user" (Markus and Silver 2008, p. 623). Symbolic expressions reflect what the technology epitomizes for organizational actors, and the subtle conclusions actors reach about its value[1].

[1] From this point on, we use the terms "technical features" and "symbols" interchangeably with "functional affordances" and "symbolic expressions" for simplicity.

Collectively, narrative networks and AST provide a powerful set of tools to understand the interplay between technology and routines. The technical artifact provides new technical features but at the same time, it often eliminates affordances available in the old routine, forcing the flow of the story to take a different path. If the new system affords a direct substitute, then the routine can proceed unchanged. But if the new system offers a different set of affordances, then the routine needs to change to accommodate the new capabilities.

Changes in routines are reflected in the breakpoints in the narrative network; a specific functional event in the routine where the sequence of actions is altered. Affordances allow new functional events to be inserted into an existing network or old ones removed, thereby triggering the occurrence of the breakpoints. However, the mere existence of a functional affordance does not guarantee a new functional event. Affordances become functional events - viable paths in the narrative network - only when the people carrying out the routine choose those paths (by exercising their agency). In other words, organizational actors purposively direct the path along which the narrative progresses by intentionally choosing to co-opt (or ignore) the affordance into their routine.

The structure of the narrative is also influenced by symbolic expressions that come to be associated with the technology and its affordances. Within the range of potential narratives that can surround a routine when a technology intervenes, some may be associated with positive symbols and "happy endings" for the participants while others are not. Positive symbolic expressions tend to reinforce the desirability of certain pathways in the narrative networks by associating them with valued outcomes, and other paths become suppressed. Using the concept of functional events, positive symbols increase the likelihood of certain functional events being selected (and the plot proceeding in a particular direction) while negative symbols decreases the likelihood of functional events being selected (and the new routine along that path fails to be established).

Summary

Our review of the literature reveals a paucity of in-depth studies on the interaction between routines and new HIT in clinical settings. To the degree that HIT disrupts established patterns of work and this disruption is frequently implicated in the failure to successfully implement HIT, understanding these interactions and how to orchestrate the interplay successfully is of significant theoretical and practical relevance. While most existing studies treat technology as exogenous, where users have limited influence to modify the technology (e.g., CT scanner), we examine the more complex bi-directional interactions based on AST and narrative networks. We also highlight the importance of agency in influencing the co-evolution of the technology and the narrative[2].

3 Method

3.1 Background: Research site

To examine the technology implementation process, we conducted an extensive longitudinal field study in 2008 by exploiting the unique opportunity that arose when a large hospital shifted its method of clinical documentation (e.g., patient charts and flow sheets) from a paper-based system to a computerized documentation system (CDS). The hospital is located in a major metropolitan area and features approximately 250 beds and 50 Intensive Care Unit (ICU); overall, the hospital staff treats more than 350,000 patients annually. Prior to the implementation of the CDS, the hospital's HIT infrastructure included a computerized provider order entry system and electronic medical administration records.

[2] Representative prior work that draws upon our reference theories is provided in online appendix 1.

The clinical documentation process has always played a pivotal role in hospitals' daily operations, serving as both an information repository and a means of facilitating communication among different care providers. Patients' treatments, progress, and health status are documented in charts that are filled out by physicians, fellows, medical residents, and other healthcare providers; the typical patient chart contains patient flow sheets patient progress notes, consultation sheets, and lab forms. Virtually all daily routines for in-patient care involve accessing, creating, consulting, and utilizing these documents.

For centuries the practice of medicine has been dominated by a preponderance of paper and physicians have used the traditional pen and paper method for the above-noted documentations. However, although inexpensive and easy to use, paper documentation systems have a number of serious limitations, including the problems of illegible handwriting, search difficulty, and limited capability to share and distribute patient documents among a dispersed group of healthcare providers. With the advent of CDS, the traditional pen and paper method of documentation was replaced by computers. Physicians can document a patient's progress using "electronic progress notes," nurses update flow sheets via computers, and certain fields can be updated automatically via integrated biomedical devices.

The CDS implementation resulted in several radical changes in the work environment, including the replacement of paper-based notes with electronic notes, the introduction of new equipment such as tablet computers, and increasingly ubiquitous mobile access carts (also known as Computers on Wheels or COWs). The dramatic shift from paper to digital medical recordkeeping dislocated existing routines and led to emergence of new patterns of work and interaction to which organizational actors had to adjust.

Despite its extensive impact on the clinical workflow, it was evident that by the end of the study, the CDS had been successfully integrated as a coherent component of the hospital's daily routines. The Chief Medical Informatics Officer (CMIO) received a prominent award from a large medical informatics association in recognition for the implementation, and the hospital was featured on the vendor's website. To further establish the validity of this assertion, we conducted two additional tests, both of which suggested that the original goal of using the CDS to improve efficiency and quality of care has been achieved (see Appendix 2). From this evidence we concluded that the hospital's CDS implementation effort offered a rich setting in which to address our research objective of understanding successful HIT implementation process.

3.2 Data collection

We learned about the hospital's plan to implement the CDS in January 2008, five months before the targeted implementation date. This allowed us sufficient time to plan and design the study carefully. Our observations occurred primarily in the Intensive Care Unit (ICU). We conducted three preliminary rounds of observations, where an off-duty attending physician accompanied us to explain the roles of the clinical teams, the tasks they were conducting, and the documents they generated. Based on the observations, as well as extensive discussions with the CMIO and three other attending physicians in the hospital, we selected two routines as the primary targets of study: the rounding routine (also known as "rounds"), and the consulting routine (also known as "consult."). These routines were selected for three reasons. First, they are among the routines most frequently conducted in the wards and have direct implications for efficiency and quality outcomes. Second, both routines involve significant use of the CDS, providing an ideal setting in which to examine the implementation process. Third, while the two routines share many common characteristics, there are substantial variations in terms of complexity. This enabled the detection of consistent patterns of successful change, and thus increased our confidence in the generalizability of our findings.

Rounding is an important activity in which the team of health care providers in charge of the same patient or group of patients meets to integrate and exchange information, as well as to develop a collaborative plan of care. A team is typically composed of an attending physician, a fellow, two or more residents, nurses, and at times other healthcare providers and support professionals such as the respiratory therapist, dietitian, and social worker. During the rounding process, the team relies heavily on patient documentation for making clinical decisions. Because the facility is a teaching hospital, the rounding routine also plays an important educational role; it provides on-the-job training and apprenticeship opportunities for fellows and residents to learn from the clinical skills of the more experienced attending physicians. The discussions between the healthcare providers in charge of the care delivery process are also recorded in the patient documentation.

Situations often arise in which the rounding team decides to consult a specialist about certain patient conditions (e.g., hematology, or infectious disease), an action which in turn triggers the consulting routine. Consult physicians who specialize in the treatment of certain diseases are called in by the attending physicians for consultations, or “consults” as they are colloquially known, in order to provide diagnoses and advice. In each instance, the consulting routine typically involves one consulting physician who comes to the ward to read the patient documentation, check the patient, and produce a consult note.

Formal data collection began two months before the CDS implementation and lasted until six months after the implementation. This extended time span covered the entire implementation process and allowed us to compare the changes to routines that were induced or influenced by CDS deployment. During this period, we followed every aspect of the two routines closely and applied semi-structured interview protocols to guide interviewees through topics such as whether their perception of their tasks had changed due to CDS use and whether (and how) their interactions with other healthcare providers had evolved. We also solicited open-ended comments about the system both before and after implementation, as well as user evaluations of the system. The observations and interviews were conducted using purposive sampling to cover a wide range of clinicians from various departments and areas of specialization. Due to stringent patient-privacy constraints, it was not possible to tape-record the observations or interviews. However, we took copious notes during the shadowing process and recorded extensive field notes on a daily basis.

To obtain detailed measures of the workflows in place at the hospital and the impact of CDS on these workflows, we also conducted a time-motion study designed to capture the activities and interactions that constitute each routine using a specially developed software program. The nature of each activity and the time at which it occurred were recorded using the software run on a tablet PC, creating a behavioral record for each routine that was observed. This allowed us to better measure the internal dynamics and performance of the routine. Because the rounding routine is too complicated to capture each individual's activities, we applied this approach to the consult routine, as it is relatively simple, yet still entails significant complexity in the form of interdependencies and interactions.

We further obtained and analyzed two sets of archival data. The first set of archival data consisted of campaign materials, meeting notes, and training manuals used early in the implementation cycle, before the system went live, that we used to help gain a better understanding of the features in the technology and the messaging surrounding CDS. The second set of archival data consisted of meeting notes, technology patches, releases, and change requests for the system. This set of archival data assisted us in mapping the evolution of the system in regard to features and functionality. In total, we collected data from 123 hours of observation, 168 hours of time-motion study, 50 interviews, 63 meeting notes, and a readability test on the notes from a panel of 6 physicians on 201 notes. The multi-stage, multi-method approach supported a detailed analysis of the impact of IT manifested in changes to routines, as well as the dynamic process of implementation. The data collection process is summarized in Appendix 3.

3.3 Coding

Data coding and analysis proceeded in multiple steps. First, we reviewed the initial interviews to identify the micro-level processes related to CDS for each routine. Second, we documented the routines using narrative networks and identified the ways which CDS was used with respect to functional events. We corroborated the findings with the archival data on feature requests to identify when a feature was added to create a new functional event. Third, we identified the occurred changes to the narrative network and labeled breakpoints. Finally, for each breakpoint, we mapped the processes identified in the first step and affordances in the second step.

We further conducted interviews with three senior physicians who are familiar with the processes to verify our understanding. Based on the interview data, we identified the processes related to CDS and compared the interview notes before and after the implementation. For the second step, we identified the changes to the consult routines where we highlighted the breakpoints in the old routines. To illustrate the analytical process, consider a specific breakpoint

(Figure 2, Step I) that is caused by a new feature in CDS which allows the consult physician to receive the consult orders in their electronic inbox. This function afforded by CDS is then triangulated with the archival data on the features of CDS to verify if the feature was an original implementation or a new feature request. This step is repeated with all the breakpoints identified in the narrative network. Using the interview data, we identified the changes in the interpretations (i.e., symbols) of the system as they evolved, temporally juxtaposing them with affordances and breakpoints.

4 Analysis and findings: Routinization of HIT

We begin with the narrative networks associated with the focal routines to illustrate the changes that occurred during the successful implementation of the CDS. Then, a detailed description of the adaptation processes is provided in order to examine the dynamic evolution between routines and CDS. We finally propose a dynamic process model of adaptive routinization for successful HIT implementation.

4.1 The transformation of routines

4.2 Changes in rounding routines

Figure 1 depicts a representative rounding routine prior to CDS implementation. A typical morning rounding routine begins with the attending physician assembling all of the team members precisely at 7 a.m. As a group, the team then begins to move from bed to bed, observing and interacting with all of the patients under their care. At each patient’s bedside, the resident (or medical student) in charge of that patient reports on the patient’s status to the rest of the team. Key pieces of patient information, such as vital statistics and any significant events that occurred to the patient since the last round are consolidated and presented. Once the resident completes the description, the attending physician comments on the resident’s train of thought if necessary, and discusses the plan of care with the team. This sequence of activities is repeated as the team visits all of the patients assigned to them.

--INSERT FIGURE 1 ABOUT HERE--

The narrative network in Figure 1[3] deconstructs the routine into specific functional events and helps to identify paths of information flow, including, most notably, the extensive use of documentation and recordkeeping in the rounding process. These events include: 1) the attending physician looking for a yellow sheet called the "progress note", 2) the residents reading from scraps and pieces of scratch paper on which they have jotted down notes, and 3) other team members recording on their own set of "progress note" documents. Finally, the rounding routine ends with the team filing all of these individual progress notes into the patient chart.

The introduction of CDS intervention caused significant changes in the rounding routine in both its sequence and action patterns (see Figure 1, Steps 1-11). We isolated changes to the routines using breakpoints in the narrative networks. As described earlier, breakpoints refer to the first action in a series of actions or events in routines that are displaced in the emerging narrative network as a result of new features. Three breakpoints occur in Steps I, III and IX in Period 1 (Figure 1) because of the elimination of duplicate progress notes. In the past, each health care provider created his or her own notes about each patient on yellow sheets (Figure 1, Steps III, VI and IX), and as such, it was not possible to share notes in real time. After CDS was implemented, the capability of electronic notes enabled by CDS spawned new viable paths. For example, members of the rounding team can create an electronic note from scratch or create a

[3] In figures 1 and 2, the narratives are at the routine level. While our data support the construction of narratives with greater granularity, this level of abstraction offers simplicity and comprehensibility advantages that were important as we sought input from the actors involved to verify our understanding. This level of abstraction also enabled us to map user requests for additional technical capabilities made in later stages of the implementation cycle.

note copied from a previous note. Members of the rounding team then select a path creating the functional events. Often paths that substituted the actions in the old routine were chosen. As a result, we observed several new functional events being created and the sequence of the old events altered. First (see functional event in Figure 1, Step 1), the resident prepares the note in the CDS interface, a system to which all team members have immediate access. Then, the fellow and the attending physician edit the existing note, rather than starting from scratch, and each creates their own notes (Figure 1, Steps 2, 9, 10 and 11). It is also interesting to note that post-CDS implementation, there was a significant increase in the number of COWs used during rounds (Figure 1, Step 6), which affects other communication channels such as face-to-face discussions.

4.3 Changes in consulting routines

A typical consulting routine is triggered when the attending places a consult order requesting that a consulting physician with a specific clinical specialty visit a patient (Figure 2, Step I). After receiving the consult order, the consulting physician schedules the visit. Once the consulting physician arrives in the ward, she locates the patient chart and flow sheet and reviews the information in them (Figure 2, Step III).

--INSERT FIGURE 2 ABOUT HERE--

Unlike the rounding teams that have persistent and repeated interactions with the patient, the consulting physician typically is not familiar with the patient's situation and history. As such, the process of providing specialized recommendations involves significant labor-intensive information gathering and provision. In most instances, there are many different types of information that the consulting physician must gather, including the patient's medical history and physical (H&P) information. Prior to CDS implementation, this process was often complicated by legibility issues, or information buried deeply in an inch-thick patient chart. To help attain a comprehensive understanding of the patient's health status in a timelier manner, the consulting physician obtains some or all of this information from the nurse or the patient's family, sometimes placing a call to the rounding team to gather additional information and insight. Finally, the consulting physicians file the consult sheets in the patient chart and charge for the consult, which completes the consulting routine (Figure 2, Steps X and XII). The consult sheets are later reviewed by the requesting physician.

Similar to the pattern that emerged from the rounding routine, we identified a number of significant post-CDS changes to the consulting routine, both in terms of its sequence and action patterns. These changes occurred as a result of six initial breakpoints in the original narrative network. Pre-CDS, the consulting physician often received calls throughout the day from other healthcare providers requesting consults (Step I). After CDS was implemented, a new technical feature - the inbox feature initiated a breakpoint in Step I. Consulting physicians could now receive consult orders in their inbox, allowing them to check all orders in one consolidated step (Figure 2, Step 1). Another breakpoint occurs in these steps because of new features afforded by CDS. (Steps II - VI). For instance, in the past, the consulting physician had to be physically present at the patient's bedside in order to gather information about the patient. With CDS, the consulting physician can view patient documentation at any system terminal, regardless of the user's physical location (Step 2). A series of new functional events (or pathways in the narrative) now becomes feasible. After going through the history of the patient, the consulting physician can go to the ward to check on the patient. Alternatively, the consulting physician can choose to make use of a system function known as "task batching." As shown in Figure 2, Step

2, this process allows the consulting physician to review the electronic patient records for all of his or her assigned patients before performing another action. A similar process of task batching is then repeated for patient examinations (Figure 2, Step 6) and note creation (Figure 2, Step 8). The electronic note interface also includes a billing functionality, thereby essentially eliminating Step XII in Figure 2. Taken together, these new functional affordances shorten the sequence of the consult routine from twelve to eight steps.

4.4 Evolving narratives through functional affordances and symbolic expressions

Next, we examine the dynamic unfolding of the narratives surrounding the two routines, and deconstruct the underlying processes. Our analysis starts with the pre-implementation phase and concludes with the successful incorporation of CDS into the routines. We temporally sequence the dynamic adaptation process into three phases: *pre-implementation, transition, and refinement*. In the following discussion, we illustrate the ways in which routines and HIT interact with one another via functional affordances and symbolic expressions, and delineate the role of agency in these interactions. An overview of the evolution of functional affordances and symbolic expressions is presented in Figure 3.

--INSERT FIGURE 3 ABOUT HERE--

Pre-implementation phase

As defined by Markus and Silver (2008), symbolic expressions are the often-intangible messages that a system communicates to its users, in this instance, the healthcare providers (i.e., the physicians and nurses). Interestingly, while not expressed in the current AST framework, we find that users' symbolic expressions related to the system were formed even before their actual interactions with the system, mainly through marketing materials and advocacy by key members of hospital management. For example:

> *"[The hospital] is moving forward with implementation of an electronic medical record and new technologies have been designed for [the hospital]'s clinicians to provide quality care in the safest environment… [The Hospital] Initiative will transform how [the hospital] delivers health care…Enhanced documents will be efficient, thorough, accurate, concise, well organized and will focus on collecting information once and using it many times… this technology greatly enhances the hospital's workflow.."*

The messaging above is rife with symbolic expressions: "…a relational concept bridging IT artifacts and how users may interpret them" (Markus and Silver, 2008, p. 623). The communicated symbols implicitly embed a comparison of the functional affordances granted by paper documentation versus CDS. It is well known that information in handwritten notes is often illegible, incomplete or inaccurate. The relatively low information quality of paper-based record systems can lead to extra work for caregivers to find information (often involving calling the provider who generated the note in question). Furthermore, the diminished legibility of handwritten notes can lead to misinterpretation, resulting potentially in medical errors and malpractice claims. It is also difficult to share paper-based documentation, particularly if someone else is already using it. Compared to paper documentation, CDS can improve the quality of patient care by ensuring the creation of uniformly legible notes, allowing system users to obtain up-to-date information to support improved clinical decision-making, and granting access to all patient information in order to help medical personnel gain comprehensive insight into each patient's progress. CDS also promises to improve the efficiency of the entire healthcare team through the reduction of duplicate and redundant tasks and the speedier creation of notes[4]. The positive symbols of efficiency and quality were promoted extensively and deliberately by hospital management during the training period.

Although the core routines used in the provision of care had not yet changed during this phase of the process, active preparations for the transition could be observed. For example, residents were made aware that after CDS was implemented, they would need to prepare an initial note for the rounding team, and as such, they would need to arrive at the ward earlier than usual. The CDS training sessions (4-10 hours) were mandatory for all practitioners, and it appeared that the changes in routines were well-understood and thoroughly prepared for prior to the actual date of implementation.

Transition phase

In May 2008, the hospital's CDS went live with a "big bang" implementation, and paper notes were no longer used. Immediately, we were able to observe routines undergoing transformation. The majority of the routine changes (specified in Figure 1 and 2) occurred as planned, without resulting in chaos. The most obvious benefits, such as improved documentation legibility and information timeliness, were realized as soon as the CDS replaced paper notes.

Strikingly, we observed a significant shift in what CDS symbolized for users post go-live. Despite the benefits realized, many users' overall impression of the system changed from positive to negative. Rather than agreeing with the rosy picture of CDS' purported ability to improve efficiency and care quality, many users began to regard the new system as causing unnecessary delays and promoting incompetence. What caused this shift in symbolic

[4] A comparison of functional affordances offered by paper notes and by CDS through various stages of the implementation process is provided in Appendix 4.

expressions? Our data implicated two factors as the key drivers of reframed symbols: loss of performance, and missing features.

Loss of performance

In sharp contrast to the performance gains promised during training, at the beginning of the transition period, the new technical features resulted in longer times to complete similar tasks, and greater likelihood mistakes. Some of this performance loss is inevitable due to learning, such as becoming accustomed to new functions like typing and navigating the new interface. These initial challenges are illustrated in comments made during interviews.

> *"It takes a lot longer to chart, input data. I must care for patients, then devote at least 1/2 hour more to charting."*

> *"…when you're presenting [the patient summary], the computerized note has such poor flow and does not read easily so you end up regurgitating what's on the screen instead of presenting something that actually makes sense and that you've been able to think about."*

When the rounding team began to make extensive use of the COWs, new functional events occurred in the evolving narrative networks. Due to increased staff reliance on the COWs, their batteries were being drained more frequently and more recharges were necessary. If the battery drained completely while a note was being composed in the system, all data could be lost, a situation that caused delays and understandable frustration. The competition to gain access to a functional COW unit intensified, causing tension between teams. As one physician put it:

> *"The team focuses on whose COW is it, they distinguish this is my COW and this is your COW instead of, this is a COW for our job". (Attending physician)*

Users also discovered that during peak times of note creation, the CDS' central database did not have enough bandwidth to support and process requests in a timely manner. This led to negative symbolic expressions: a "loss of efficiency" as the healthcare providers complained that they often had to wait as long as one minute for the digital notes to load. Some personnel believed that this slowdown in efficiency might even influence the quality of care:

> *"…You also don't synthesize the information as well and don't think about the plan of care as well because you become so caught up in the details of writing the note"*

The digital notes enabled a new capability that was not available in the paper notes: directly incorporating content from previous notes. This feature is called "copy-forward". Several residents and consultants started to utilize this function as it makes note creation more convenient, and the narrative network gained a new functional event (Figure 1, Step T2) where healthcare providers used the copy-forward. However, this functionality forwarded too much information if care was not taken to uncheck the options. This led to obsolete information – information from the note created yesterday was automatically imported into the new note. Healthcare providers became concerned as they felt that this process may increase the likelihood of errors. This again led to negative symbols, as illustrated in the comment below from a physician:

> *"I also have had to increase my time in educating the residents about this (more than before), because the copy forward function is very easy and lucrative for them to use, and because there is wide diversity among attendings as to how complete and accurate a note must be before signing (in my specialty, also from other services). Some residents have accepted the challenge, but some still jump to the shortcut and propagate poor, old, or inaccurate info day to day."*

A few attending physicians even went as far as to suggest that the system was “dangerous”.

> *“…it has come to a point of danger because residents cannot effectively complete notes, are careless when we copy forward notes, and are unable to efficiently view vitals and I/Os etc.”*

Overall, the new functional events which increased the amount of time required to operate some components of the CDS system, and the increase in errors due to new features was at odds with the original symbols of “efficiency and quality,” causing frustration and disenchantment.

> *“Although the concept [of CDS] is great, the implementation and reality is not! It takes me 2-3 times longer to document and there are too many ways to do the same thing.”*

Missing features

The most damaging complaints about the new system stemmed from difficulties experienced in the process of integrating CDS into existing functional events. Several affordances that were present in the paper system were absent in CDS. One such affordance is the ability to track the communications between healthcare providers about the patient. In the paper-based notes, there is a dedicated area to record who has communicated with whom. This type of information could not be recorded easily in CDS. As such, the healthcare provider was unable to keep track of which important pieces of information had already been conveyed and which still needed to be relayed, often resulting in unnecessary duplication of efforts. Likewise, in the consult routines, physicians also experienced missing essential functions such as missing billing codes which prevented them from submitting the billing request and made it hard to execute the routine, (see Figure 2, Step T9).

The direct influence of past action patterns that comprised the staff's longstanding routines was evident in the modifications that were requested and later incorporated as technical features of the software artifact. In both consulting and rounding routines, physicians often write, underline, and draw diagrams on the paper-based notes that they create. Because the healthcare providers were accustomed to the format of the paper-based notes, i.e., a blank, lined page upon which they could free-write without constraint, the new interface proved to be peculiarly disorienting for some.

> *"The formats of notes, H&Ps, etc is not user-friendly or eye-pleasing. For example, why can't we easily bold, or increase the font, in certain parts of our notes?" (Healthcare provider)*

The introduction of COWs also created unexpected disruptions in tacit aspects of the hospital's existing routines. To illustrate, during rounding, users now focused more attention on the screen of the COWs to obtain information (Figure 2, Step T6), reducing the amount of eye contact between the attending physician and the residents. Several attending physicians expressed discomfort with the change because the system's large LCD panels obstructed their view and increased their uncertainty as to whether their messages and intended meanings were being understood by other members of the rounding team. As before, these CDS-induced changes led to the emergence of negative symbols.

> *"Monitors disrupt the team dynamics and the large number of COWs impedes movement. There is no eye contact, blocked view and I am not sure if they were paying attention…" (Attending physician)*

In summary, the CDS intervention instigated significant changes in the existing narratives of the routines. The users experienced loss of performance and missing essential features that were previously well integrated into their workflows. This, in turn, produced a significant shift in the initially positive symbols of the system. What would prevent this process from spiraling towards an implementation failure? We found that the incompatibility between CDS and routines triggered purposive action in the form of agency on the part of key actors, who both enacted changes to the routines as well as requested changes in functional affordances in the restoration process.

Restoration

Given the time-sensitive nature of clinical routines, it is imperative to restore the functions disrupted by the new system in a rapid manner. In the weeks after CDS implementation, we observed that many of the system's missing features were reported to the vendor. It was also noted that the vendor proved to be very responsive to these requests; some features and added functionalities were incorporated into CDS as a result of these staff-generated change orders. For example, the slow speed in opening notes was addressed by increasing the bandwidth and throughput assigned to CDS.

However there are features that take time to add in. Confronted with missing functionality that prevented the execution of the old routine, healthcare providers proactively started to modify the narrative by introducing new functional events. In particular, functional events in the form of workarounds emerged to enable routines to be performed. Workarounds have been defined as alternative approaches to obtaining the same goal (Ash et al. 2004; Vestal 2008); we observed several user-initiated workarounds to cope with exceptions encountered during the use of CDS (Halbesleben et al. 2008; Patterson et al. 2006). For the missing features such as tracking communications, the physicians and nurses figured out to use the text field where providers "free write" specific instructions. Consulting physicians put the missing billing codes into the free writing part. The rounding team also created a number of workarounds to help ameliorate the problems that they encountered. An instance of a particularly creative solution was with respect to the battery life problem of the COWs. Healthcare providers created a workaround by connecting all the COWs with electric extension cords and then plugging the end unit into a power outlet (Figure 1, Step R6), thereby charging all of the connected machines simultaneously.

The introduction of workarounds imposed some constraints on the prevailing routine, necessitating further modification to the narrative and resulted in the addition of new functional events. With respect to the COW battery-life workaround, the team was forced to perform their duties in a coordinated way so that the electrical cable connections between the units would not be interrupted. As another example, further discipline on documentation was developed for the correct use of copy-forward to reduce errors. The physicians and nurses were forced to change their way of writing a note: instead of saying "today", they needed to specify the exact date so that when the note was copy-forwarded, readers knew exactly what date the content was created (Figure 1, Step R2).

Refinement phase

Once the basic functions for patient care had been restored, a new level of change to CDS and routines began to emerge in what we term the "refinement" phase. First, healthcare providers explored the use of the more advanced features in CDS, using hitherto unused functional affordances that, in turn, resulted in new narrative fragments or "chunks of technology in use" (Pentland and Feldman, 2007, p. 788) that were added to the narrative. Second, an overarching symbol of "performance improvement" began to be associated with the CDS. This new vision further led to the development and use of new features and capabilities within CDS.

Taken together, these changes further enabled performance improvements for both the rounding and consulting routines, helping the hospital to achieve their goals of safe, timely, high-quality patient care. We delineate each of these interactions in turn.

In the refinement phase, several advanced features in CDS began to be identified and accessed more frequently by hospital personnel, and were used extensively from this phase onwards. In both the rounding and consulting routines, healthcare providers developed new activities in routines that made fuller use of the new and advanced technical features of CDS. To illustrate, in one specific example of this change, staff members began to develop their own templates for notes; a new functional event that helped reduce the number of clicks and keystrokes that physicians had to employ when creating a note.

Another advanced feature, remote access, allowed both attending and consult physicians to give remote instructions to other healthcare providers for patient care from another location. This functional event proved to be extremely valuable in the provision of timely patient care. Remote access afforded physicians the ability to remotely monitor their patient's progress based on up-to-date information such as vital signs. In combination with the graphing capabilities of CDS, the new functional affordance enabled physicians to respond quickly without having to be physically present at the patient's bedside.

> *"If you have VPN [virtual private network], you can do a lot from home. …for certain things like if I get called at night, I don't come in so it's easier. In the past it was harder to see things because it's hard to know what they are asking." (Fellow)*

Similarly, consult physicians made use of the system's new technical features to change their consulting routines and develop new ways of working, such as "task batching" (see Figure 2, Steps 2 and 6), a process that allowed for time savings and a reduction in cognitive processing loads.

> *"A lot of changes... such as not looking for the chart by the patient bedside every patient encounter, rather I do it in the morning.. I conduct a preview of new cases... by the time I sit down in the office I visualize H&Ps first.."*

With the addition of new functional events, negative symbols began to attenuate as healthcare providers discovered and grew accustomed to new capabilities within the system.

> *"There are a lot of positive results from CDS and it seems to be getting better and easier to use as time goes on."*

As the symbols became more positive, we observed enhancements to the narrative networks and further changes pertaining to the functional affordances of CDS being made as a result of new routines. Strikingly, these changes to existing routines led to more innovative requests for affordances than those originally implemented. Pre-CDS, the attending physician had to flip through thick stacks of paper notes in a binder to look for pertinent patient information during rounds. After CDS was implemented, the attending physician could obtain up-to-date information on each patient simply by clicking on various sections of the patient chart interface in CDS (Figure 1, Step 6). Although this new routine represented a significant improvement over the old way in terms of efficiency and clinical decision support, attending physicians further refined it by proposing the development of a new CDS feature called the "Clinician Summary"; this feature allows the physician to obtain an aggregated view of all relevant patient information (e.g., patient vital signs, lab results, active medications, fluid intake and output, etc.) on a single page that is accessible using one click. This led to further performance improvements in terms of information readability and efficiency during the rounding routine.

We observed similar refinements in the consulting routine during this period. One example included the creation of a new function that simplified the process of requesting a consultation with a specialist. When an attending physician generates an electronic order for a consult, they must specify the rationale for generating the request, which can often be quite elaborate. The completed consult order is received by the consulting physician, who then enters the same reason in the note to respond to the request. During the refinement phase of the CDS implementation process, a new function termed “automatic import of consult reason” was requested by the consulting physicians. After this feature had been developed and activated, a new functional event was created where the consulting physicians were able to automatically import the consult reason stated by the requesting physician into their own note, thereby increasing the efficiency of the consulting routine (see Figure 2, Step 8.3).

In parallel with the addition and deletion of functional events during the refinement phase, new symbolic expressions emerged and evolved. For instance, the system came to be associated with symbols related to professional cues such as autonomy and teaching. By exploiting the affordances available in CDS and executing functional events that helped to increase availability and timeliness of patient information, some consulting physicians felt that they had reclaimed a higher degree of autonomy. Commenting on this reinforced professional identity during interviews consulting physicians noted:

> *“When functioning as a consultant, being able to see the medical record from any location is very useful.” (Consulting physician)*

“I really like it... I mean you know I can work anywhere, sometimes when I am in the train, or I can even find it at home, I can write a note anytime." (Consulting physician)

In the rounding routine, a new symbolic expression related to “teaching” was generated during the refinement phase. CDS came to be regarded as an instructional tool that could enhance student learning by offering new ways of creating notes and engaging in other tasks that would help prepare the students for their future roles as attending physicians. In light of this new symbolic expression, attending physicians, fellows, and residents proposed that a series of new training-oriented functionalities be implemented into the CDS system. This symbolic expression was later reified by additional changes requested by the attending physicians. As a result, new technical features were incorporated into the system, creating new functional events.

“We are using it as a teaching tool so that we can show the trainees where we edited their notes, so that they can see the difference... we are trying to do that with different colors so that we can see in colors where the attending edits”. (Attending physician)

The symbolic expression of “teaching” as a CDS benefit was consistently reinforced by further requests for features For example, to strengthen residents’ ability to make better clinical decisions, two more fields were added to the progress note – “differential diagnosis” and “diagnostic reasoning.” These fields were designed to help residents identify and distinguish between factors that either support or refute one’s clinical assessments so that they can sharpen the skills necessary to synthesize patient data and create a thorough and sound assessment and plan of care.

Agentic action in adaptation

Thus far we have described the dynamic microprocesses of change to functional events, functional affordances, and symbolic expressions triggered by CDS that eventually resulted in the emergence of new routines for rounding and consulting. Given that the narrative associated with these routines experienced many breakpoints as documented above, there are other possible paths along which the "story" could have developed. What explains this particular evolution and not another one? How did the final structure of the narrative emerge? Pentland and Feldman (2007, p. 788) note: "Within the physical and technological limits of the situation, the connections between events ("what happens next") are enacted in each case by the contingent actions of the participants." Consistent with their theorizing, our analysis suggests that agency played a critical role in steering the narrative towards a happy ending. We observed two types of agency that were particularly critical in guiding the change process in the right direction: leadership and personal innovativeness.

First, leadership emerged as a critical factor during the transition period. Among all the different functional events and viable paths that exist as possibilities, the ability to interpret certain pathways in the network as valuable and to communicate this interpretation to others is essential. For example, hospital leadership was quick to take action to curb the negative symbols that had developed in response to early loss of performance experienced while adjusting to CDS use. The attending physicians, who assume a leadership role among the rounding teams, also helped to shape the perceptions of healthcare providers toward CDS. Several initiatives were developed to help maintain the momentum of CDS use and to address and allay dissent that had begun to ferment early in the implementation. The attending physicians became key agents in advocating the proper use of certain features and reframed the symbolic cues associated with the technology. At the same time, they educated other healthcare providers about the channels through which to provide feedback. The attending physicians also played a crucial role in influencing team members by providing informal CDS training sessions to rounding members before the daily rounding routine commenced. Commenting on the ways in which team members' CDS use was influenced by the attending physicians, one interviewee noted:

> *"It really depends on who [attending] is on top and what they demand". (Attending physician)*

Attending physicians are often held in high regard by other healthcare providers because they comprise the upper echelon of the hospital's rigidly hierarchical organizational structure, and as such, their attitudes and actions can play a significant role in influencing those around them (Mannion et al. 2009; Wright et al. 1998). Organizational leaders and authority figures who positioned themselves as proponents of CDS helped those who were deeply skeptical about the perceived benefits of the system to begin to build tentative optimism about the implementation process.

> *"A lot of these have to be attending driven because they (rounding team) don't have a sense of direction". (Attending physician)*

Second, as evidenced in the creative requests from users in the refinement phase, a growing sense of personal agency among the hospital's healthcare personnel in the form of personal innovativeness provoked experimentation with new affordances and functional events. This experimentation added new functional events and trimmed specific fragments of actions in the old routine which, in turn, led to additional refinements in existing routines and the discovery of new functional affordances and workflow enhancements. Not only were users creating shortcuts and workarounds, they were finding ways to use the system for other than its explicitly intended purpose.

> *"Before I usually did a skeletal note based on the data I got on pre-rounds. Now I print the notes and jot down notes on them. So this is the note and I kinda put out a quick note*

so that when I sit down in the office I just update and I copy the note from yesterday and add that...so this is the pre-rounding stuff which I put at the back and I go up in the office.. It will be quicker for me to put this in."

"Searching for patient with just DOB (Date of Birth) and first name when some of the time the last names are spelled incorrect or parents have changed child's last name. Also, the ability to search for a patient with just DOB was something that could not be done in EPRS or compendium in past". (Consulting physician)

In short, personal innovativeness in users' actions was crucial in driving continued routine change by exerting pressure on the functional affordances that connect technology and organizational routines. The more exploration a user engages in, the greater the chance he or she will be able to determine which features of the system work most effectively in a given situation. Experimentation also reveals new possibilities for what the technology can accomplish, as Pentland and Feldman (2007, p. 792) observe: "...using is designing, and designing is emergent." Once individuals feel confident enough to explore and deploy more fully the features of the innovation, their feelings of self-determination (Deci and Ryan, 1985) are amplified. Here, routine change is perceived to be crafted volitionally, and the user experiences a greater sense of control of the change when it is induced by the technology, rather than being externally imposed. In other words, agency in the form of innovative behaviors gives rise to users taking greater ownership of the technology. In the CDS context, this was particularly important given the well-documented clinician concerns about the effects of HIT on the performance of their clinical work.

The refinement phase of CDS is continuous and on-going. The hospital has created a special task force including several physicians to observe the impact of CDS on everyday workflows and provide recommendations on modifications in either the routines or HIT. Through this new type of agency, we have observed further changes to both routines and CDS, such as reinforcing the use of advanced functions including macros and pre-completed notes and creating a list of common diagnoses to speed up the search process. Collectively, these actions have been critical in helping medical personnel integrate CDS more fully into their daily routines.

4.5 A dynamic, process model of adaptive routinization of HIT

Based on our observations and analysis, We construct a dynamic process model for successful HIT implementation summarized in Figure 4; we label the process adaptive routinization of HIT. It begins with an existing focal work routine that is associated with a narrative reflecting how it is performed. When the technology intervenes, it disrupts the narrative and yields new potential pathways. The technical artifact comes imbued with symbols for users: some intentionally communicated, and others developed as users attempt to make sense of the intervention. Symbols can range along a continuum from negative through neutral to positive: the valence and direction of the symbols determine which of the alternative paths get selected. Agency in the form of leadership helps shape and frame symbols and associates certain pathways with valued outcomes. Agency in the form of personal innovativeness both shapes and creates symbols, and also new narrative possibilities. The process plays out in multiple cycles of micro-adjustments that collectively propel the narrative towards the desired outcomes.

--INSERT FIGURE 4 ABOUT HERE--

Several aspects of the process depicted in Figure 4 are worth underscoring. We first identify the two major channels through which HIT and routines interact: functional affordances and symbolic expressions. When HIT is implemented, it is often used to replace an existing legacy system. HIT typically alters system functionalities in two ways: removing functionalities afforded by the existing system, and adding functionalities available in the new system. Functional affordances transform existing routines by changing an organization's repertoire of actions and sequence of functional events. The selection and combination of new functional events result in varying routine sequences and structures (Pentland 2003). An important relationship discovered in our data is that HIT implementation influences routines via changes in affordances. Because our study was longitudinal and we observed this occurring in situ, we can tentatively advance causal assertions. In the case of CDS, the steps in the routines and channels of communications were both changed due to new functions, as illustrated in Figures 1 and 2. For example, the introduction of digital notes led to reductions in redundancy and increased efficiency. After developing basic familiarity with the system, users also began to take advantage of more advanced functional affordances that would not have been possible prior to CDS implementation, such as introducing physician remote access into the consultation routine.

Unlike studies focusing on clinical technologies (Barley, 1986, 1990; Edmondson et al 2001), wherein the technology artifact being studied is difficult to alter, we find that in the case of HIT implementation, the technology is also being altered in the routinization process. Since existing routines have been developed in tandem with the legacy system, after the new system is implemented, it is likely that some functionalities that are essential to carrying out existing routines will be unavailable. Thus, in order to continue to perform these routines, it is necessary to modify the IT artifact to quickly address the incompatibility with existing routines. In the later stages of adaptation, users' attempts to make further refinements to the routines can often lead to more advanced customization of the technology.

A second important channel through which IT artifacts and routines interact is symbolic expressions. We find that the symbolic expression regarding a technology can begin to form long before actual implementation. For example, during the training period, we observed that users had already formulated clear ideas about CDS's intended purpose of improving efficiency and quality of care. Over time, these symbols motivate the users to fine-tune their routines. In turn, we observed that routines generate new symbols about the IT artifacts, as evidenced in the teaching example. Improving the hospital's teaching capacity was not part of the original goals of the CDS implementation; rather, it came to be added by users as they grew more accustomed to using the system to perform the rounding routine. We further find that symbolic expressions can change sharply over the course of the implementation phase, especially if the original (default) expectations pertaining to efficiency and functionality are not met early in the implementation process. However, these negative interpretations can be assuaged and even reversed by modifying the IT artifact, as well as by creating workarounds in routines.

As suggested by the spiral in Figure 4, we emphasize that the adaptation of HIT to health routines is not a finite, linear task. Rather, it is a continuous process with multiple rounds of iteration. This conceptualization of adaptive routinization also brings into focus the distinction between virtuous and vicious cycles. The establishment of a virtuous cycle between IT and routines can significantly facilitate the process of adaptation, as each round of interaction leads to the creation of an enhanced fit between routines and technology. In a virtuous cycle, positive symbolic expression pertaining to the system leads to greater willingness to integrate the technology into existing routines, which in turn generates positive effects on the performance of routines. Observing these desirable outcomes, users will be more willing to modify routines by selecting functional events that assist them in gaining more from the technology and vice versa, and over time, these mutual reinforcements lead to the successful routinization of the technology. The way that such a virtuous cycle played out in the CDS implementation process is summarized in Figure 5.

--INSERT FIGURE 5 ABOUT HERE--

The virtuous cycle is critical for successful HIT implementation, but it should not be taken for granted. It is just as easy to envision scenarios where the interplay between the narrative, technical features and symbols degenerates into a vicious cycle. The vicious cycle is likely to start at the beginning of the transition period, when the loss of efficiency and lack of access to familiar features can lead to negative symbols. This negative image of the new system can, in turn, discourage users from modifying routines to accommodate the system. If the new system is not used to perform existing routines, users lose valuable opportunities to familiarize themselves with the system, which prevents them from customizing the system to restore missing functionalities and makes it impossible for them to gain the degree of confidence necessary to begin to explore new features. This vicious cycle then results in more accumulated discontent and might even lead to the abandonment of the new system.

Our model highlights the role of agents in enabling the virtuous cycle. We isolate two important sources of agency, leadership and personal innovativeness, as well as two major ways through which agency can begin to take effect, namely, workarounds and customization. In the current study, the conceptualization of the key role of leadership was derived largely from the influence of the attending physicians. Because of the "clan culture" that is prevalent in many healthcare organizations, we observed that attending physicians' attitude towards the new system played a disproportionately important role in terms of exerting social influence either in favor of or against CDS. Further, the support of attending physicians was particularly important during the initial transition period, when a vicious cycle was most likely to take hold. The positive influence via agentic leadership actions has synergistic effects on other agents: it can engender a growing sense of personal innovativeness among users and their agency can help to allay and even reverse instances of negative symbolic expressions by encouraging team members to create workarounds for the missing features in the new system. The significance of personal agency is most prominent in the refinement stage, as users begin to micro-adjust both the IT artifact and routines to achieve better fit.

The final outcome of agentic action is that pathways that are less desirable come to be associated with negative symbols ("…why would you want to use copy-forward when it can possibly compromise patient safety?") and get trimmed from the narrative networks with a result that the narrative is steered towards value-creating outcomes. To further illustrate this notion of a vicious cycle and the significance of agency, consider a scenario where leadership and personal innovativeness are absent. In that case, a user is unlikely to find ways to improve the system and may abandon the functional event. A vicious cycle develops as negativity spreads laterally to other healthcare providers. These negative symbols can be amplified across different functional events in the narrative network associated with the technology. Similarly, a vicious cycle can ensue when there is a lack of leadership. Without a strong leader who can improve the morale of using the system and establish protocols to improve the system, there is a downward spiral as negative symbols develop and accumulate. This negativity stymies other functional events afforded by the introduction of IT. For example, if there was a lack of leadership when bad feelings started to sediment with the new functional event associated with the copy forward feature, the pathways leading to this functional event could be trimmed from the narrative network, causing a total abandonment of the system. Or consider the consulting routine. If the consult physician does not attempt to look for workarounds to resolve problems with billing, negative symbols arise and successive narrative networks cannot proceed. The physician is then very likely to revert back to paper based billing.

To summarize, our conceptualization of the adaptive routinization process not only shows the mechanisms involved in the evolution of hospital routines during HIT implementation, it highlights the need to "manage" these mechanisms - functional affordances and symbolic expressions, through agentic action. How effectively these mechanisms are managed may well determine whether a virtuous or vicious cycle gets set in motion by the introduction of a new technology.

5 Discussion and conclusion

In this paper, our primary research objective was to unravel the mechanisms underlying successful implementation of HIT. Based on a detailed longitudinal field study in a large hospital during a period in which the hospital implemented a computerized documentation system to replace all paper-based charts, forms, and notes we find strong evidence that routines are changed after HIT implementation and evolved through dynamic interactions with technology. We identified three stages in HIT implementation. The pre-implementation stage is when users form initial symbolic expressions about the new system, and plan for the changes to existing routines. The transition stage is focused on restoring the essential functions of routines, while the refinement stage revolves around fine-tuning and exploring new capabilities. During the transition stage, the intrusion of HIT causes disruptions to daily routines and ignites physician resistance. In all of the stages we observed, there are rich interactions between routines and technology via symbolic expressions and functional affordances. Further, we identify the pivotal role of leadership and personal innovativeness in enabling a virtuous cycle of co-evolution between routines and HIT. Both forms of agency were instrumental in determining which paths in the evolving narrative network endured and became routinized. While user innovativeness helped to reconfigure the performative aspect of routines, leaders' attitudes helped shape symbolic cues to reduce the dissonance between the performance expectations of the system and the reality of system capabilities.

Methodologically, this study demonstrates that organizational routines viewed as narrative networks provide a rich and promising lens through which to understand the HIT adaptation process. We find that routines are not simply passively disrupted by technology, but rather interact through functional affordances and symbolic expressions. These interactions trigger agentic forces that actively modify the newly implemented IT artifacts. We formally define these mechanisms between IT artifacts and routines, and signify their importance in the adaptation process. The integration of the two hitherto distinct literatures on organizational routines and the revised AST may, in part, represent a tentative step forward to "theorize the fusion of technology and work in organizations" (Orlikowski and Scott 2008 p. 434).

The findings in this study also contribute to the routines literature. We extend the previous work on technology-enabled routine changes by explicitly delineating the impact of routines on the technology artifact. Our model reveals the iterative processes through which HIT is routinized, which has not been closely examined before. We also isolate the two mechanisms via which routines interact with technologies to change narratives, and the role of agency in enabling a virtuous cycle, thereby providing a dynamic picture of the technology routinization process.

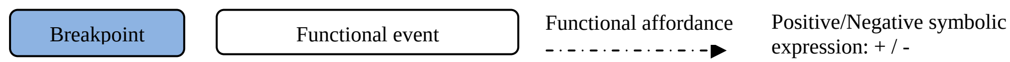
For AST, we enrich the framework in Markus and Silver (2008). AST defines functional affordances and symbolic expressions as the relationship between the IT artifact and its users. We expand the domain of users to include routines. More importantly, we find that in the process of HIT adaptation, functional affordances and symbolic expression are generated not only from the IT artifact that is being implemented, but also from the legacy system that is being replaced. Especially during the transition period, users' discontent is driven largely by the *lack* of functional affordance, which also changes their symbolic expressions vis-à-vis the new system. This insight extends understanding of the sources of functional affordance and symbolic expression. Finally, our finding that affordances and symbols are not static but rather, can be dynamically modified by agentic action throughout a technology implementation cycle sheds new light on the nature of these constructs.

Given that broad-based adoption of HIT in hospitals is imminent, our study carries significant practical value in helping hospitals successfully implement new HIT. At its core, our adaptive routinization model suggests that continuous and deliberate adaptation is necessary for HIT to be effectively routinized. The mechanisms of the interactions between IT and routines, as well as the types of agency identified in the model, should help hospitals better manage the implementation process to achieve more desirable outcomes. For instance, agency in the form of leadership and personal innovativeness can help restore the efficiency losses that are often related to new system implementation and help alleviate user resistance, which is critical to the successful adoption and implementation of HIT (Jha et al. 2009, DesRoches et al. 2008, Scott 2005). As implied by our findings on personal innovativeness, we also suggest that healthcare organizations implementing HIT need to shift the mindset of employees from “What is the system supposed to do?” to “What can I do with the system?”

The software application we examined is a commercial package from one of the major vendors in the industry. To date, most studies on HIT focus on in-house developed systems in leading institutes, and there has been a notable lack of research on the implementation of commercially developed HIT (Chaudhry et al. 2006). Given that commercially developed systems will likely represent a feasible option for most healthcare organizations, we hope that this current study can help to advance collective understanding of this important issue. Specifically, we suggest that commercial application vendors should keep the realities of clinical routines in mind when designing the systems, and pay more attention to enhancing customization capability.

There are several limitations of the study. Although we believe the model is sufficiently generalizable to apply to other types of HIT and contexts where routines are pervasive, readers are cautioned to remember that this study was based on one instance of successful adaptation of one specific technology. Further, there might be other factors that are important to the process of HIT implementation, but are not included in our model. Such factors may include organizational culture, financial resources, technology infrastructure and capacity, externalities such as peer institutes and regional health information organization (RHIOs), etc. Nevertheless, we believe this research represents a first step toward understanding how to manage the virtuous cycle of HIT implementation, and we hope to ignite more interest in applying a routines perspective and AST to the study of HIT implementation.

Figure 1: Rounding routine



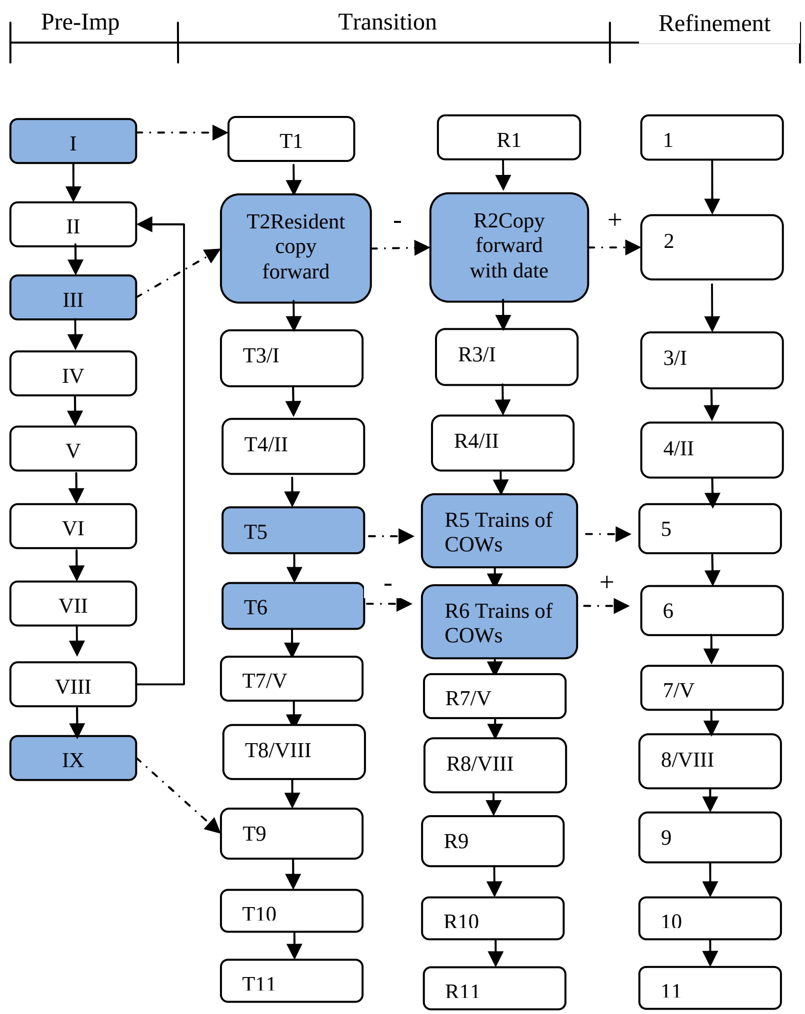
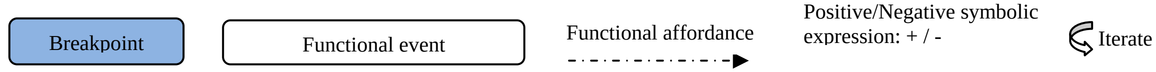
Pre-CDS	Rounding routine	Post-CDS
I. Attending assembles rounding team. II. Team goes to patient bedside III. Resident narrates patient's progress and all members of the team either grab a new note or use paper or use existing progress note to take notes. IV. Attending discusses plan of care with team using patient chart and radiology/labs. V. Attending talks to and examines patient. VI. Attending and team members look for new note. VII. Attending and team document plan of care. VIII. Team leaves patient's bedside. IX. Team looks for patient chart and files notes.		1. Resident looks for open terminal. 2. Resident creates new note using templates / pre-completed notes. 3. Attending assembles team. (Similar to Step I in pre-CDS routine) 4. Team goes to patient's bedside. (Similar to Step II in pre-CDS routine). 5. Resident narrates patient's progress using tablet and attending refers to tablet while team takes notes using COWs. 6. Attending discusses plan of care using tablets, radiology/lab results using COWs. 7. Team talks to and examines patient. (Similar to Step V in pre-CDS routine) 8. Team leaves patient's bedside. (Similar to Step VIII in pre-CDS routine) 9. Resident looks for open terminal to edit electronic note. Note is forwarded to fellow. 10. Fellow edits notes resident created and forwards note to attending. 11. Attending edits notes and signs off note.

Figure 2: Consulting routine



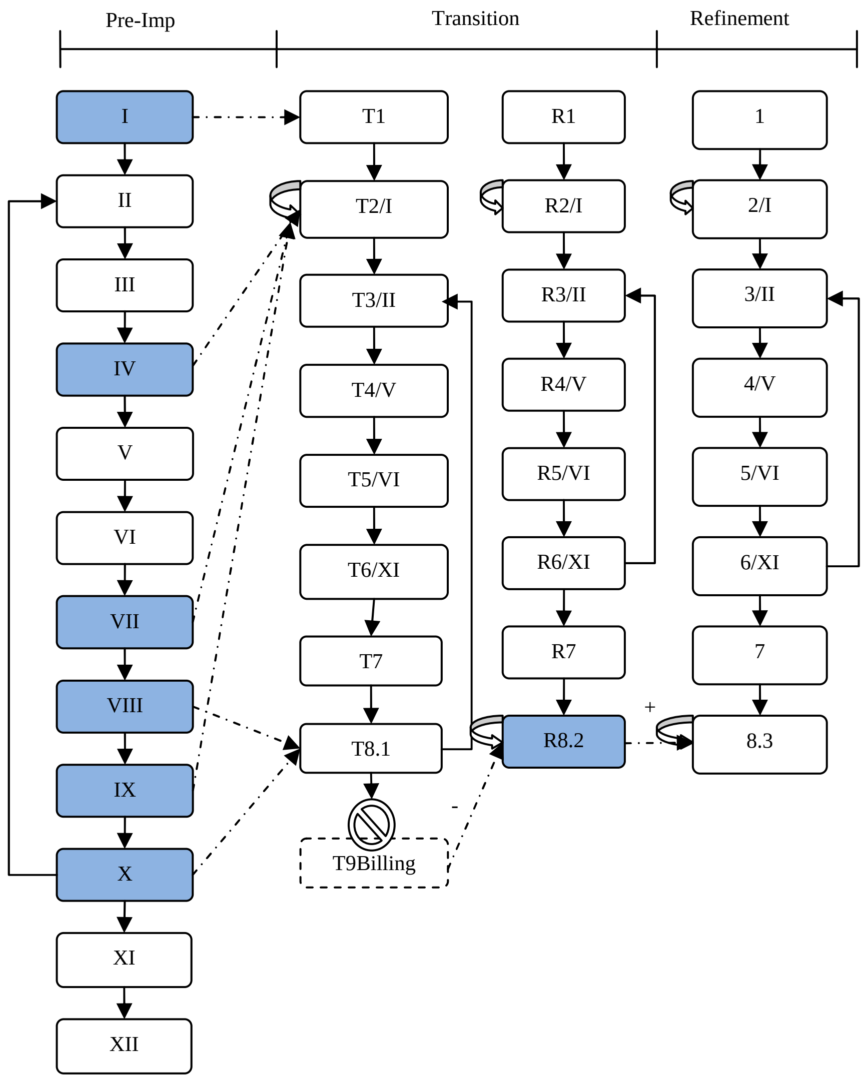
Pre-CDS	Consulting Routine	Post-CDS
I. Consult physician receives call/page. II. Physician goes to patient's bedside. III. Physician looks for flowsheet and patient chart. IV. Physician checks flowsheet and patient chart. V. Physician finds out more about patient through nurse or family. VI. Physician talks to and examines patient. VII. Physician looks for consult sheet. VIII. Physician writes plan and recommendations on consult sheet. IX. Physician looks for patient chart. X. Physician files notes into chart. XI. Physician leaves patient bedside. XII. Physician submits form for billing.		1. Physician receives electronic order. 2. Physician checks electronic patient record. Repeat if more than one order. 3. Physician goes to patient's bedside. (Similar to Step II in pre-CDS routine) 4. Physician finds out more about patient through nurse or family. (Similar to Step V in pre-CDS routine) 5. Physician talks to and examines patient. (Similar to Step VI in pre-CDS routine) 6. Physician leaves patient bedside. Repeat 3-6 if more than one order. (Similar to Step XI in pre-CDS routine). 7. Physician looks for terminal. 8. Physician creates and enters electronic note into electronic chart. 8.1 Physician cannot bill because of missing billing codes. Call billing department. 8.2 Physician free-writes billing code into form. 8.3 Physician creates form with automatic imports and templates. Billing code restored.

Figure 3: Evolution of Functional Affordances and Symbolic Expressions

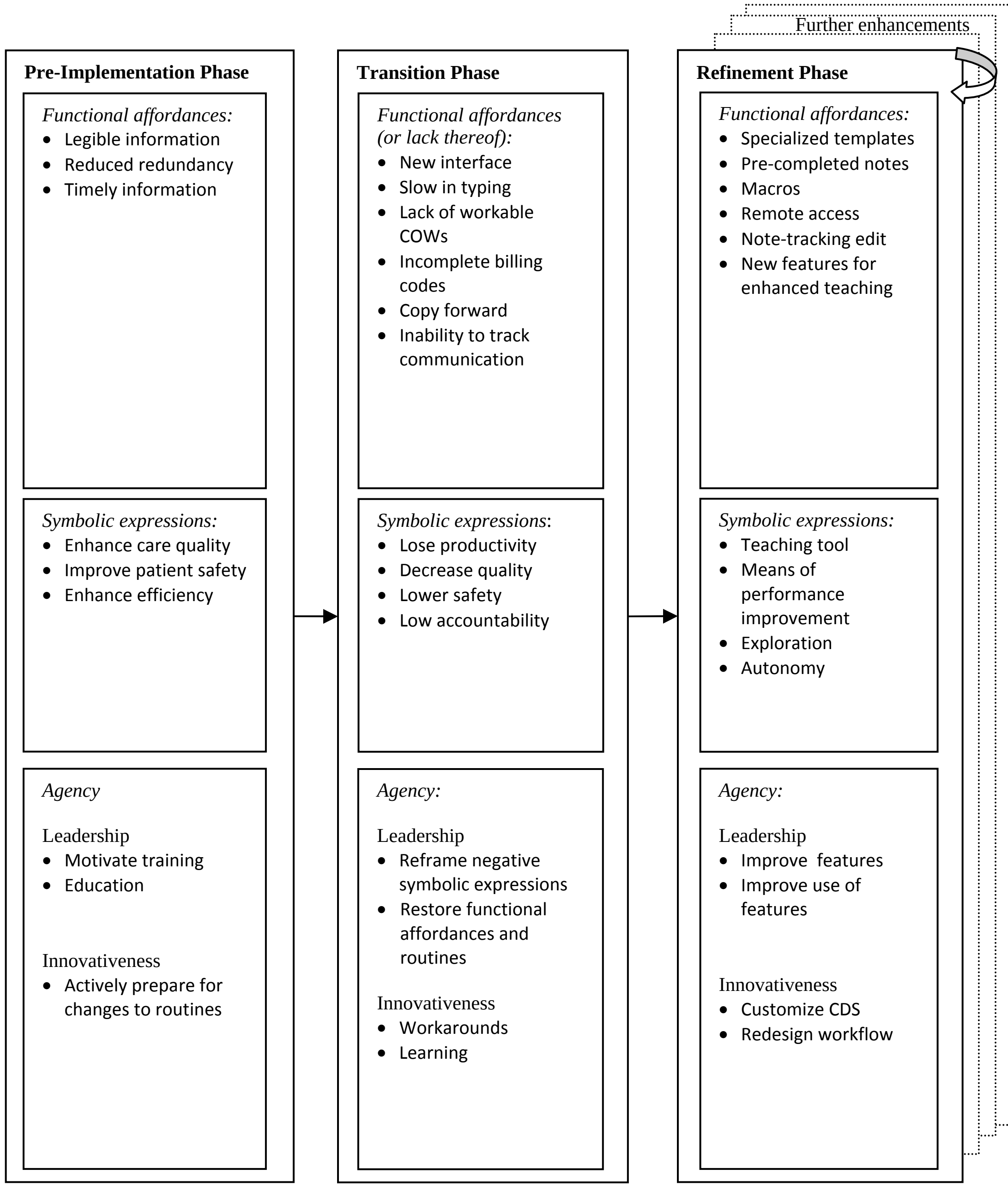


Figure 4: A Dynamic, Process Model of Adaptive Routinization of HIT

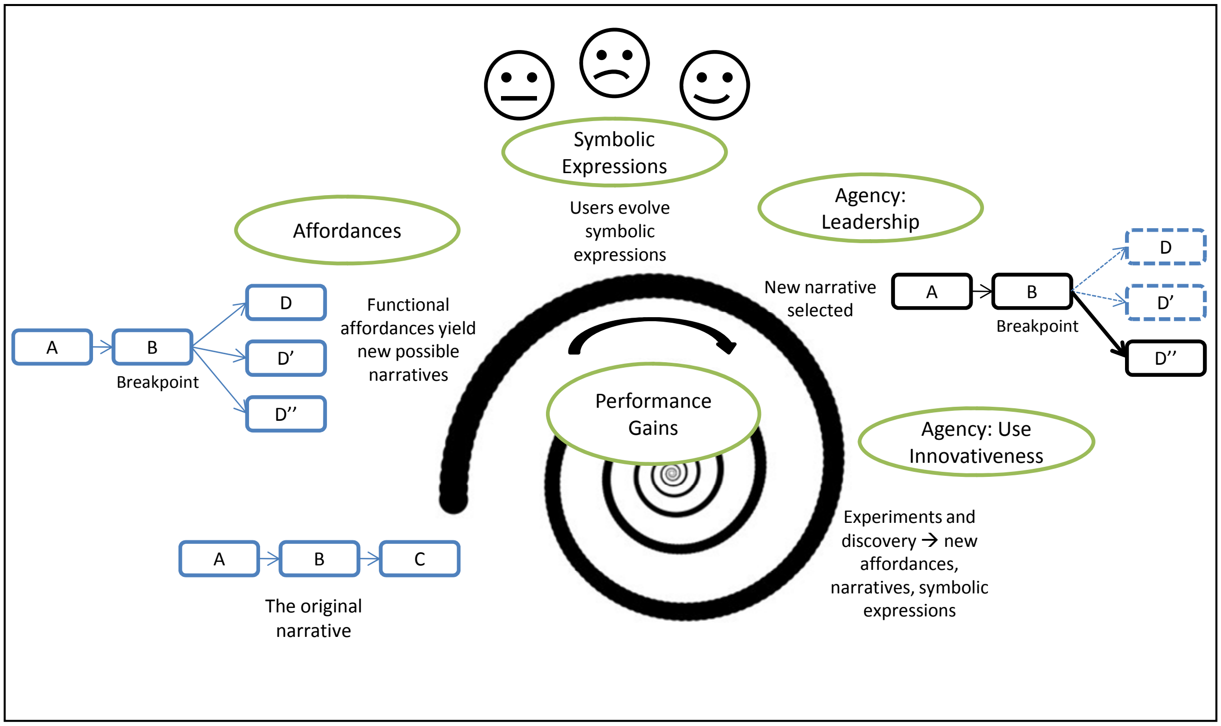
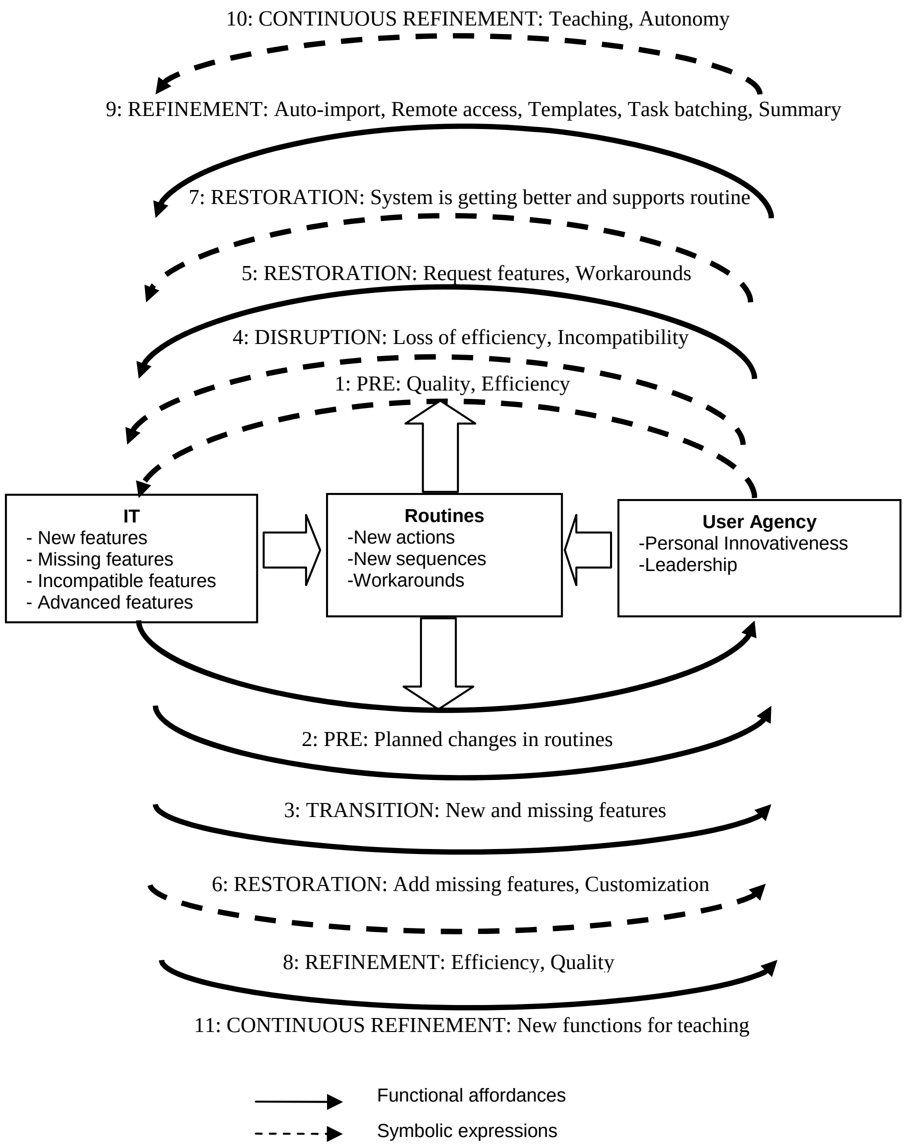


Figure 5: The Virtuous Cycle of Adaptive Routinization for CDS



Appendix 1: Summary of Related Literature

Research Stream	Sources	Major Concepts	Key Points	Gaps
AST	Markus and Silver (2008); DeSanctis and Poole (1994)	• Functional affordance, defined as the relationship between "potential uses" or affordances of the technical objects and a specified user group. • Symbolic expression refers to the "communicative possibilities of technical objects" for a specified user group.	• Refinement of original AST model. • IT is a "socio-technical assemblage". • IT artifact can contribute to "IT use patterns" and "second order effects". • Relationships between technical artifact and users: functional affordance and symbolic expression. • Importance of social structure and technology.	• Does not consider the sequence of actions taken by users. • Non-users are not taken into account. • Path dependency across multiple actors (including non-users) not addressed. • Limited to users or user groups, rather than series of actions in an organizational content (i.e., routines) • Limited application in health care.
Routines	Feldman and Pentland (2003); Cohen (2007); Pentland and Feldman (2007); Pentland and Feldman (2008),	• An organizational routine "is a repetitive, recognizable pattern of interdependent actions, involving multiple actors". e.g. academic hiring routine • Technology can disrupt existing routines. • Environmental factors influence the establishment of new routines.	• Routines are repetitive pattern of actions. • Routines involve multiple actors and interdependence. • Routines are a source of flexibility and change. • Ostensive and performative aspects of routines are recursively related. • Subjectivity, agency and power are central to the flexibility and change in routines • Structure refers to the ostensive aspect of routine. • Agency is the "choice of actions" and "reflexive self monitoring" of those actions, "always have organizational and institutional structures that define a set of possibilities for the participants."	• Limited studies on the co-evolution process of IT artifacts and organizational routines, especially how routines influence the design of IT artifacts. • Factors that influence the above dynamic process not addressed in healthcare. • Limited studies on ICT's impact on healthcare routines.
Health Care and Health Informatics	Greenhalgh (2008)	• Routines are abundant in healthcare setting.	• Routines are important for health care delivery outcomes	• Nuanced relations between HIT and routines not explicated.

(pertaining to the unique characteristics of healthcare)			
	Niazkhani et al. (2009)	• The importance of clinical workflow in healthcare settings.	• Review paper. • Authors call for more research to explore the “multidimensional and collective impact” on collaborative workflow dominant in healthcare.

Appendix 2: Results from Readability Study and Time Motion Study

Table 1: Readability Test

Evaluation Criteria	Paper	n	CDS	n	P value	t
Overall note quality score	13.233	73	14.445	128	0	4.565
Mean completeness	6.932	73	7.563	128	0	5.2793
Mean readability	6.301	73	6.883	128	0.0024	3.0757

Table 2-A: Time Motion Study

Type of Activity (measured in minutes)	Paper	CDS	P value
Computer	10.8	17.2	0.00
Paper	18.1	4.5	0.00
Communication	22.4	16.9	0.20
Patient exam	7.5	5.0	0.11
Miscellaneous	3.9	3.1	0.89
Total time taken for visit	58.1	41.5	0.05

Table 2-B: List of Activities Captured in the Time Motion Study

Category	Activities
Paper – Read:	Chart, Data, Consult Note, Progress Note, Goal sheet, Patient List, Own Notes, Forms, Other
Paper - Looking For:	Chart, Data, Consult Note, Progress Note, Goal sheet, Patient List, Own Notes, Forms, Other
Paper Filing:	Consult Note, Progress Note, Goal Sheet
Paper – Writing:	Consult Note, Progress Note, Goal Sheet, Own Notes, Form, Other
Procedures:	Exam Patient, EKG, IV, Joint Inj/ASP, Lab Test, Other
Personal:	Eating, Restroom, Blackberry, Palm/Diary, Other
Talking:	Attending, Fellow, Nurse, Resident, Patient Family, Patient, Consultant, Other Staff for Pt, Radiographer, Other
Walking:	Inside (patient bedside), Outside
Phone:	Call someone, Get Results, Schedule Test, Receive Page, Personal, Other
Computer – Read:	System Log In/Out, Data, Radiography, MAR, Email, Forms, Other
Computer – Read (Phase 2):	Consult Note, Progress Note, Flowsheet, Assessments, Transfer or Discharge Notes, Patient List, Order, Other
Computer Search (Phase 2):	Consult Note, Progress Note, IView, Assessments, Transfer and Discharge, Patient List, Order,
Computer – Search:	Literature Search, Data, Lab Result, Radiograph, Patient Record, Colleague, Forms
Computer – Writing:	Note, Orders, Email, Forms, Other
Computer – Writing (Phase 2):	Consult, Progress Note, Flowsheet, Assessments, Transfer and Discharge, Forms, Orders, Email, Billing, Patient List, Other

Appendix 3: Overview of Data Collection

Activities	Method	Use of Data in Analysis
Project inception	Interviews with Chief Medical Information Officer and five attending physicians.	Identify routines to observe.
5 visits to the hospital	Observations	Gain familiarity with the context. Select routines for study.
3 preliminary rounding routines 3 preliminary consult routines	Two authors attended these rounds and consults taking copious notes.	Develop understanding of existing routines.
Introductory session on CDS	Two authors attended this session to understand the features of the new system.	This session and prior consult routines sessions were used to develop time and motion software for consult routines.
Training sessions	Two authors attended training with healthcare providers.	Understand healthcare providers' satisfaction with the old system and the pre-CDS symbolic expressions associated with the new system.
Pre-CDS observations	The first author shadowed 27 physicians for 51 patient visits. Time and motion data and field notes.	Narrative networks drawn from data. Identify and understand the old routines.
Pre-CDS interviews	The first author interviewed 17 clinicians.	Identify and understand the impact of functional affordances and symbolic expressions of the new system.
Post-CDS observations	The first author shadowed 21 physicians for 43 patient visits. Time and motion data and field notes. Narrative networks drawn from data.	Identify and understand the changes to the routines after CDS was implemented using narrative networks.
Post-CDS interviews	The first author interviewed 11 clinicians.	Identify and understand the micro-level processes and the impact of symbolic expressions and the functional affordances of CDS to routines.
Archival data	Archival data from training manuals, change requests, super user meetings notes Archival data such as employee newsletters	Identify original features in system and change requests prior to CDS implementation. Identify how system evolution shaped employee perceptions.

Appendix 4: A Summary of Functional Affordances over Time

Functional Affordances	Paper	CDS at Disruption and restoration phase	CDS at Refinement phase
Facilitate communication of entire health care team through			
- availability of information	N.A.	Medium	High
- monitoring	Low	N.A.	High
Specialized note template	Low	Low	High
Facilitate efficiency of entire health care team through			
- reduction in duplicate tasks	N.A.	High	High
- search patient information	Medium	Medium	High
- copy forward	Low	High	High
Facilitate safe patient care through			
- legible information	N.A.	High	High
- timely information	Medium	High	High
Facilitate efficient patient care through			
- availability of information	Medium	High	High
- speed of entering information	High	Low	Medium
- timely sharing of notes	Medium	High	High
Provide clinical decision support through			
- timely notes and patient information	N.A.	High	High
- centralized information	N.A.	High	High
Be fully compliant on information completeness through			
- auto-population and automatic import of data	N.A.	High	High
Support coding and billing services through			
- automatic integration of billing service with note	N.A.	Medium	High
Provide accountability through			
- signing off	Low	Low	High
- authorship of edits	N.A.	Low	High

Appendix 5: Definition of the Terms in Figure 5

Pre-Implementation Phase

Functional Affordances (as a result of the following features)

- Legible information: CDS will afford readability
- Reduced redundancy: CDS will afford the use of the same note by multiple health care providers
- Timely information: CDS will afford the storage and access of the up-to-date notes simultaneously

Symbolic Expressions

- Enhance quality care: With CDS, the quality of care of the hospital can be enhanced
- Improve patient safety: With CDS, patient safety can be improved with superior documentation
- Improve efficiency: With CDS, workflows can be more efficient

Agency

- Leadership:
  - Motivate training: Motivate other healthcare providers to attend training
  - Education: Educate healthcare providers the correct way of using certain features
- Innovativeness:
  - Prepare for changes to routines: Healthcare providers took the initiative to prepare for changes

Transition Phase

Functional Affordances

- New interface: CDS features afforded too many different possibilities and created uncertainty
- Slow in typing: CDS required all notes to be typed
- Lack of workable COWs: Frequent breakdowns of COWs, limited affordability of CDS
- Incomplete billing codes: CDS failed to afford billing for certain consults
- Copy forward function: CDS afforded speedier creation of note but also introduced too much and obsolete information
- Lack of ability to track communication: CDS failed to afford use for certain actions or sequences in old routine

Symbolic Expressions

- Lose productivity: CDS symbolized lost productivity and efficiency
- Decrease quality: CDS symbolized decrease in the quality of care
- Lower safety: CDS increased chances of errors
- Low accountability: CDS failed to track who has edited notes leading to lower accountability

Agency

- Leadership:
  - Reframe negative symbolic expressions: Attending physicians helped to reframe negative symbolic expressions
  - Restore functional affordances and routines: Attending physicians helped propose restoration of features which were available in old routines
- Innovativeness:
  - Workarounds: Healthcare providers used alternate ways to achieve basic functionality
  - Learning: Healthcare providers actively learned to use the CDS

Refinement Phase

Functional Affordances

- Specialized templates: Each specialty was afforded their own templates
- Pre-completed notes: CDS allowed healthcare providers to use pre-completed notes
- Macros: CDS allowed storing chunks of information for reuse
- Remote access: CDS afforded accessibility of patient chart from anywhere for patient care and clinical decision support
- Note-tracking edit: CDS afforded trackable edits to allow senior physicians to indicate where they have edited on resident notes
- New features for enhanced teaching: CDS afforded fields to provide deeper thinking and a structured way of writing notes

Symbolic Expressions

- Teaching tool: CDS became a tool for teaching
- Means of performance improvement: CDS enhanced performance
- Exploration: CDS had new capabilities
- Autonomy: CDS improved professionalism

Agency

- Leadership:
  - Improve further the features and use of these features: More feature requests and changes proposed to enhance CDS and the ways of using CDS
- Innovativeness:
  - Customize the CDS: Customized templates in CDS for use with sub-specialties and role
  - Redesign workflow: Proposed and develop new and innovative ways to use CDS

Essay 2: The Social Value of Online Health Communities

Abstract

Evidence suggests that, as a result of heterogeneity in access to information, significant health disparities exist between rural and non-rural residents. Rural areas are generally less endowed with medical professionals, and rural residents often lack medical information and thus, tend to have a poorer health status compared to their urban counterparts. Technology-mediated online health communities may be able to bridge this gap as they provide a platform whereby patients from urban and rural areas are able to interact and exchange information. The extent to which online health communities can bridge the rural-urban knowledge divide has not been addressed in prior research. To answer this question, we uncover the underlying social structure of the online health community using a dataset collected from a rare disease community. We examine the support patterns between the patients participating in the online community through social network analysis and stochastic network models, and find evidence that urban patients tend to respond to the threads posted by rural patients about symptoms, nature and prognosis of disease. We also find evidence of strong emotional support provided to rural patients by urban patients compared to the exchanges that occur only among rural patients. Our findings suggest that the use of online health communities has the potential to create social value by leveling the rural-urban health information gap.

1 Introduction

Health disparity refers to the situation where inequitable medical access occurs as a result of some “social, economic or environmental disadvantage” (Koh et al., 2011). Geographical location can create a significant disadvantage for rural residents and increase the health divide between urban and rural residents. Previous studies have shown that rural communities experience greater health adversity such as prevalence of obesity, higher rates of cancer, heart disease, diabetes and injury-related deaths, and higher prevalence of chronic conditions. Prior research also finds evidence that certain types of cancer occur with higher frequency in rural areas and that detection among rural patients takes place at a late stage due to a lack of access to appropriate health care (Lengerich et al., 2005). Collectively, these studies suggest that patients suffering from various diseases in the rural areas are worse off than patients living in urban areas.

The “health divide” between rural and urban areas has been attributed to multiple factors such as the lack of health care workforce in the form of trained medical professionals, limited health programs for rural area patients, and even lower standards of care (United Health, 2011; Baldwin et al. 2010). Other reasons include the scarcity of access to medical facilities and information availability leading to lower awareness for health and in turn, poorer health outcomes (Berkman et al., 2011). The problem of the health service gap is a critical one; indeed, one study suggested that the needs of rural and urban cancer patients are different (Mercuri and Kallady, 2005). Rural patients raised concerns about the lack of medical resources such as specialist cancer centers (Ricketts, 2000), and identified the paucity of information on areas of coping, treatment and side effects and home care as critical unmet needs.

The rise of online health communities enabled by the rapid growth and diffusion of the Internet provides an alternative platform as a supportive resource to ameliorate some of these concerns. On these social networking platforms, patients generate different types of online peer support through “user generated content” in various ways: they participate and exchange information on discussion forums, they create a repository of patient health records by consistently updating their progress, and they provide ratings and evaluations for various health services and providers. The capabilities offered by the social networking and information exchange features of Web 2.0 herald a unique opportunity for individuals to assume greater control over the management of their health and well-being and their interaction with healthcare organizations (Atkinson et al., 2009; Giustini, 2006; Hoybye et al., 2004; Swan 2009; Uden-Kraan et al., 2009).

Studies have shown that user generated content most commonly found in online health communities includes information about medication, experiences of disease sufferers and emotional support (Frost and Massagli, 2009). While much has been said about the potential and opportunities of online communities (Bunde et al. 2006; Coulson, 2005; Rimer et al., 2005), the extent to which online health communities can help patients remains an open question (Lamberg, 2003). Aside from a handful of studies (e.g. Anderrson et al., 2006; Klein, Richards, & Austin, 2006; Winzelberg et al., 2003), there is limited rigorous empirical evidence to demonstrate the value and utilization of these communities (Eysenbach et al., 2004; Owen et al., 2010). A recent survey (Wicks and Frost, 2008) found that patients suffering from a rare disease participate in an online community to obtain more complete information. Clearly, the social value of online communities is significant because patients benefit from the availability of support in these forums to fill their experienced void of knowledge and psychosocial needs. For instance, Uden-Kraan et al. (2008) found that information in online health communities can empower patients. Indirectly, online health communities can also benefit patients by becoming a key source of information for caregivers (Maloney-Krichmar and Preece, 2005; Perron, 2002). The platform can bridge informational gaps between rural and urban patients, more and less experienced patients, caregivers, etc. However, empirical studies that examine the patterns of informational and social support occurring within the online health communities between urban and rural patients are limited.

The objective of this study is to investigate social value creation in online health communities. Our specific focus is on the extent to which such communities are efficacious in bridging the rural-urban health divide by creating a net surplus of information and support from urban patients to rural patients. We further study the nature and characteristics of this support.

The data for our empirical analysis is obtained from an online health community focused on a rare disease. To address the research questions, we use social network analysis and exponential random graph models to analyze interaction data. To date, prior work on online health communities has predominantly focused on individual participation either at the thread or individual level and has failed to account for the entire network structure. Researchers have noted that the limitations of traditional regression models can be addressed using the exponential family distribution of random graph models (ERGM), and have increasingly begun to apply ERGM across a variety of disciplines (Ahern and Harford, 2011; Cranmer and Desmarais, 2011; Jackson et al., Forthcoming; Wimmer and Lewis, 2010) to account for higher order network structure dependencies. In this study, we use this more advanced technique to account for the entire network structure and node level characteristics. Our empirical analysis also involves using text mining techniques to classify the information exchanges that occur in the community.

We find evidence to suggest that urban patients provide support to rural patients' needs in the online health community. Individuals participating in the online community fill various informational and emotional gaps of other patients. For instance, we find that urban patients respond to rural threads related to symptoms, prognosis and nature of the disease most frequently. We also find that patient characteristics have an impact on information exchanges in the online health community. For example, disease characteristics influence the exchange of information between patients interacting on the online community. Finally, we find that reciprocity and transitivity occurs in online health communities. These results imply that there is potential for online health communities in particular to become a platform for support provision and knowledge transfer between patients, bridging the health information divide which may exist between rural and urban patients. Online communities allow rural patients to seek help online and obtain relevant health information, thereby reducing the urban-rural medical divide and in turn may improve their health status.

2 Research Hypothesis

We first discuss the concept of online social support and provide an overview of related literature. This is followed by the specific research hypothesis examined in this study and the theoretical rationale underlying it.

Online Social Support

The literature suggests that engagement and participation on online health communities offer a rich resource for social support that benefits participants. A modest but growing evidence base points to the existence of benefits such as patient literacy and the reinforcement of health behaviors as a result of receiving social support. The common forms of support through peer interactions in online health communities for the realization of these benefits include: (i) informational support; (ii) experiential support and (iii) emotional support (Bunde et al. 2006; Coulson, 2005; Griffiths et al., 2009; Meier et al., 2007; Rimer et al., 2005).

As with communities in other domains, an important benefit of participation in any online community is the wealth of knowledge and information of other participants (Shah, 2003). In online health communities, information and knowledge about the disease condition, treatments, treatment alternatives, and other disease related advice (Suls et al., 2006; Wellman et al., 1996) can be a valuable resource for patients. Experiential support is provided through the sharing of similar experiences making patients feel less lonely in the process. Exposure to and interaction with “similar” others can enhance the salience of experiential support. Benefits of such support include better coping capability, enhanced well being and improved quality of life (Hogan et al., 2002).

Emotional support refers to the provision of care and comfort and is characterized as a type of psychosocial support. Franks et al. (2004) suggests that there is a link between emotional support and enhanced self efficacy and better coping capability. Overall, it appears that online health communities provide a rich resource for social support that can benefit patients. However, the extent to which this support exists between different types of patients in online patients communities remains an open question.

Location Effects

As noted, recent studies have observed that rural patients have poorer health (United Health, 2011). Research also finds that the differences in medical care access may result in differences in the health outcomes of patients (Gamble, Eurich, Ezekowitz, Kaul, Quan and McAlister, 2011). Other studies suggest that the key needs of rural patients are the lack of specialist medical information (United Health, 2011). These studies when taken together collectively highlight that the underlying cause for the worse health among rural denizens stems from the lack of medical care and medical information availability (Lengerich et al., 2005).

It is striking that in the United States, only 11% of primary care physicians nationwide practice medicine in rural areas. It is therefore not surprising that rural counties in the United States generally have the lowest proportion of physicians per 100,000 people: the ratio of primary care physicians is about 65 per 100,000 people. Rural communities typically rely on a system of small clinics and health centers to provide primary care services. These clinics and health centers often employ non-physician health professionals to make up for the small number of physicians. The focus of local public health centers is to communicate with the public about health issues and they do not provide primary care or wellness services and lack expertise for specialized care (Woods, 2006; Reschovsky and Staiti, 2005).

The demand for healthcare services in rural communities is generally low, and even lower for specialized services such as a medical doctor specializing in a rare disease. As such, rural areas face a limited supply of specialized health care and health care professionals. In fact, anecdotal evidence indicates that even physicians in rural areas obtain useful information from patients participating in online communities. Rural patients often have to travel long distances to access these services (Sequist et al., 2011). Among rural physicians, 51% of the primary care physicians refer their patients to a distant city or town more than 20 miles from their offices. 47% of physicians think that it is somewhat difficult for their patients to obtain specialty services in the area (p.18 United Health, 2011).

Another important source of health information for patients is face-to-face support groups. Findings from previous work studying the relationship between access to such offline networks and health status find that access and participation generates beneficial impacts for health even in resource poor environments (Nobles and Frankenburg 2009). Such offline networks also serve the uninsured as a key source of medical guidance. In the case of rural patients, who often lack such access, arguably the role of online health communities becomes even more salient as it provides an alternate source of medical advice. Further, the importance of medical information from such communities is increased in the case of patients suffering from rare diseases.

As noted, online health communities can provide an alternative solution to resolve these issues by bridging the medical information gap. Given that urban patients have superior medical endowments and access to these different types of information, online health communities can become a platform serving both urban and rural patients, promoting interaction between patients and allowing information from urban patients to be transferred to rural patients. To the degree that the superior knowledge available to urban patients affords them the ability to serve as a source of expertise, while rural patients lack the necessary information to be able to contribute to the online discourse through meaningful information content, we would expect urban patients to have greater capacity and motivation to provide support to rural patients in online health communities.

But why would urban patients contribute to online health communities? What is in it for them? We draw upon studies of online communities to suggest reasons why urban patients are motivated to contribute to online health communities. Contribution to online communities is motivated by a diverse set of factors. A key and common motivation for contribution and participation in online communities is community interest (Preece, 2000). Studies have found that social norms, sense of identity and affiliation to the community are key drivers of contribution and participation in online communities (Kankanhalli et al. 2005). Another common driver for online community participation is reputation (Constant et al., 1996; Wasko and Faraj, 2000). Reciprocity, both generalized and direct, are found to account for some of the reasons why individuals contribute to such communities (Wasko and Faraj, 2005, Faraj and Johnson, 2010). Other motivations include identity verification (Ma and Agarwal, 2007) and social capital (Wasko and Faraj 2005). While all these factors may drive online contribution to online health communities, the underlying motivation for urban patients to is driven to a greater extent by the pro-social motivational factors. Patients contribute to online health communities because of community interest. The shared identity and sense of community often motivates patients participating in online health communities to help one another (Johnson and Ambrose, 2006). However, since urban patients tend to have greater medical and information access compared to rural patients, they are likely to be the providers of online support in online health communities while rural patients are the consumers. As such, we posit that there is a greater inflow of online support from urban patients to rural patients.

> H1: Within the interactions that occur in an online health community, there is a net inflow of online social support, including informational, experiential and emotional support, to rural patients compared to urban patients.

To summarize, we have argued that superior endowments in terms of access to medical expertise and knowledge among urban patients will result in them being net suppliers of support in an online health community.

3 Methods

We first describe the unique data set used in this study along with the operationalization of the measures. This is followed by a discussion of the analytical approach utilized, viz., ERGM.

3.1 Data

We use a social network approach to study the interaction patterns of the patients participating in an online heath community. This approach requires detailed data related to the exchanges that occur between participants. Data was collected from an online health community targeted at patients suffering from a rare disease during the period 25 October 2005 - 31 June 2009. The dataset was collated from a total of 3785 members´ profiles in the community and the threads and replies they posted. Given the objective of understanding the nature of interactions within the community among rural and urban patients in the United States, we refined the initial data set to exclude a set of observations as follows. We removed non-patient members, patients who did not participate in the forum, patients with incomplete data and patients from other countries, yielding a final dataset of 638 patients. We characterize the supportive tie between a patient who posts a thread and a response from another patient as a directed dyadic tie, where the arrow points towards the patient who posted the thread.

We use descriptive statistics and ERGM analysis to find evidence of support coming from urban to rural patients. Since there is a direction associated with such support provision, we use a directed graph to represent the exchanges of online support within the community. Each node in the network represents a patient who has participated in the forum. The direction of the information in the network indicates a reply to a thread: thus, when patient A replies to a thread posted by patient B, there is an arc pointing from A to B. Figure 1 shows the directed graph generated from the data which captures the dyadic nature of the threads and responses. The black nodes represent rural patients whereas gray nodes represent urban patients.

--INSERT FIGURE 1 ABOUT HERE--

3.2 Description of Measures

Our dataset provides demographic, disease and location measures (see Table 1). Demographic information includes age and gender. Disease information includes the number of years suffering from the rare disease, and the onset of the disease. Finally, the dataset contains community measures such as the number of years the patient has been a member of the online community. These measures are transformed into the network level measures.

--INSERT TABLE 1 ABOUT HERE--

Before we list the specific variables used for analysis, we explain the network level metrics that are used to derive the metrics associated with the characteristics of patients:

(i) Edges: This covariate counts the number of edges in the network.

(ii) Nodematch(*x*): This variable checks if the specified attribute *x* of both nodes is similar.

(iii) Nodeifactor(*x*): This variable calculates the number of times a vertex with a specified attribute *x* appears in an incoming edge in the network.

(iv) Nodeofactor(*x*): This variable calculates the number of times a vertex with a specified attribute *x* appears in the outgoing edges in the network.

(v) Absolute difference(*x*): The absolute difference (asbdiff) measures the difference of a specified attribute *x* variable between two nodes.

(vi) Mutual: A variable that captures reciprocity in the network, which is a network statistic equals to the number of pairs of actors *i* and *j* for which both edges in both directions exist.

(vii) Geometrically weighted edgewise shared partner distribution (GWESP): This variable provides a method for measuring the number of triangles in the network that accounts for the decreasing impact of the effect of triangles on formation of ties. Instead of counting number of triangles in the network, a distribution of counts is obtained based on each edge within the network. A parametric form of this count distribution gives each extra shared partner a declining impact on the probability of forming a tie (Goodreau, 200; Hunter et al., 2008). This metric has been shown to work well in avoiding model degeneracy, a problem commonly faced when estimating models using maximum likelihood.

We utilize the following variables in conjunction with the above metrics specifically (ii)-(v) to specify attribute (*x*) that are used in our model specification.

Location variables

"*Location*": We classify the patients´ location according to the city and state information provided on their profiles into urban or rural according to the codes found in the Area Resource File (ARF)[1] database. Next we use the directed measures: *nodeifactor(urban)*, *nodeofactor(urban)*, *Rural→Rural*, *Urban→Rural* and *Rural→Urban* in our model specification. The first metric measures the number of times a node with urban location appears of an incoming edge and the second metric measures the number of times a node with urban location appears of an outgoing edge. To illustrate, a positive coefficient for the first variable suggests that an urban recipient node increases the marginal odds of an additional edge and has a higher likelihood of receiving responses compared to a rural node (Ackland and O´Neil, 2010). If the coefficient is negative, it implies that a rural node has a greater likelihood of receiving responses compared to an urban node. By contrast, a positive coefficient for the second measure *nodeofactor(urban)* implies that urban nodes are more likely to receive responses compared to rural nodes and vice versa. Extending this rationale, if we expect that urban patients can help to fill the void of medical information availability via online health communities, the coefficient for *nodeifactor(urban)* should be negative, indicating that rural nodes are more likely to be recipients and *nodeofactor(urban)* should have a positive coefficient, indicating that urban nodes are more likely to be givers. *Rural→Rural* ties counts the number of times a

[1] City and state data from the patients' profiles were matched using a combination of Federal Information Processing (FIPS) and Metropolitan/Micropolitan Statistical Areas codes found in the Area Resource File obtained from the Health Resources and Services Administration, Bureau of Health Professions, Fairfax, Va, Quality Resource Systems,Inc; 2008

node with rural location has an incoming edge from another rural node, *Urban→Rural* counts the number of ties with rural nodes that originate from an urban node and so on.

Disease variables

"*Years suffering from rare disease*": A dyadic level variable measuring the absolute distance (absolute difference or absdiff) of the number of years that the patients had the disease. We expect that larger differences in the number of years two patients have suffered from the disease, the greater the propensity of tie formation. Thus, a negative coefficient for this variable would suggest that the smaller the difference in the number of years the patients suffer from the disease the greater the propensity of tie formation.

"*Onset*": For this particular rare disease, patients are typically classified according to the "onset" of the disease. This refers to the area of the body where they first experience symptoms of the disease. This variable allows us to control for the possible variation of disease characteristics that may occur as a result of different onsets. We use a homophilic (nodematch) metric to count the number of edges for which the two patients have the same onset area. A positive coefficient suggests that patients with the same onset area are more likely to communicate with each other in the network and therefore more likely to form a tie.

Control variables

Demographic variables

"*Age*": We use the absolute difference as a distance measure for age to control for the impact of age differences between dyads. This means that the larger the value, the greater the difference in terms of the patients' age. For instance, a negative coefficient will suggest that similarity in terms of age contributes to tie formation.

“*Gender*”: We use homophilic (nodematch) measure for gender to control the impact of gender similarities between dyads. This measure counts the number of edges for which the two nodes (patients) are of the same gender. As an example, a positive coefficient for this variable suggests that the likelihood of tie formation is higher between two nodes of the same gender.

Community variables

“*Membership*”: The absolute difference of the members’ tenure in the online community. This helps to control for the impact of members that joined at different periods and the extent to which they interact with one another.

3.3 Methodology

We first use traditional network plots and descriptive statistics[2] to examine the differences in information seeking and contribution between rural and urban users, which provides stylized facts related to information flow. We then apply the multivariate approach, which allows us to separate the effect of location while controlling for other confounding factors. One traditional approach is to examine the impact of location on the formation of tie between any two nodes using methods such as logistic regression. However, this approach imposes strong statistical assumptions. In particular, it assumes that the ties are independent observations from each other, which is required to calculate the standard errors. However this assumption is unrealistic due to the nature of network data. Higher structural dependencies such as transitivity are not controlled.

We therefore used the exponential random graph model (ERGM), a network stochastic modeling approach. ERGM is a method for deriving the likelihood of a

[2] There were no statistical differences in age, disease and community covariates between urban and rural patients.

network emerging from all the possible set of networks that could have been formed by a random assignment of ties across nodes in the network. The model class is defined as:

$$P(Y=y|X)=\exp(\Theta^T g(y,X))]/k(\Theta)$$

where Y is the random set of relations in a network, y is a specific set of relations, X is a matrix of nodal attributes, g(y,X) is a vector of network statistics, ϴ is a vector of coefficients, and k(ϴ) is a normalizing constant which ensures that the sum of probability equals one. Estimation of this normalizing constant is done with Markov Chain Monte Carlo (MCMC) methods.

The formula states that the log odds that any given edge will exist given the current state of the rest of the network is $\mathrm{logit}(Y_{ij}=1)= \Theta^T \mathrm{delta}[g(y,X)]/k(\Theta)$ where Y_{ij} is an actor pair in Y and $\mathrm{delta}[g(y,X)]_{ij}$ is the change in g(y,X) when the value of Y_{ij} is changed from 0 to 1. An overview of ERGM is provided in Hunter, Handcock, Butts, Goodreau and Morris (2008) and Robins and Morris (2007).

The online support network of the online health community is represented as a directed graph. We created several graphs using all the messages in the forum and threads of certain categories using statnet (Hunter et al. 2008). No loops are allowed in the graphs. All the graphs are binary as the ties are flattened. This means that the maximum number of ties between node *i* and *j* is at most 1. This results in a downward bias of the estimates of the models.

5 Results

5.1 Network Plots and Descriptives

We first used social network analysis tools to analyze the flow of support in the network. A summary of commonly used network level metrics is provided in Table 2.

We developed two new measures, which we term degree ratio, that will help us to visualize the social network clearly. The definitions of each of the degree ratios are as follows:

(i) Degree Ratio = (Outdegree+1) / (Indegree+1)

(i) Inverse of Degree Ratio = (Indegree+1) / (Outdegree+1)

From these ratios, we would expect that one who contributes more than he receives will have a large degree ratio and a small inverse of degree ratio. Likewise, one who receives more support than he contributes will have a large inverse ratio and small degree ratio. Again the size of the vertex reflects the value of the ratios normalized by the maximum of the ratio in Figure 2.

In Figure 2a, we observe that there are many more gray circles that represent urban patients. Further the size of gray circles or urban nodes is larger implying a larger degree ratio. This suggests that the urban patients provide support more than they receive support. On the other hand, the plot for the inverse of degree ratios as shown in Figure 2b indicates more and bigger black circles. This implies that rural patients have higher inverse of degree ratio, i.e. the rural patients receive support more than they provide support.

--INSERT TABLE 2 ABOUT HERE—

--INSERT FIGURE 2 ABOUT HERE—

5.2 Analysis using ERGM

Table 3 reports our results. We begin by proposing that the support network of the online health community is not simply random, rather it is an outcome of the dynamics proposed in the hypothesis, supported in prior research. Patients living in rural areas may have different priorities for using online health communities due to the lack of information, and the location of the patient may be a significant predictor for the formation of ties in the network. Models 1-4 provide the base model for the whole network including the location covariates. We vary the covariates such that Model 1 shows the baseline model with an edge term and Models 5 and 6 include dyadic dependent terms, reciprocity and higher order covariate for triadic closure, to control for structural characteristics. The base model, Model 1, has an *edge* variable that provides the baseline probability of one node forming a tie with another node in the network. This is a constant term that is equivalent to the density of the network.

--INSERT TABLE 3 ABOUT HERE—

Model 2 includes the individual covariates related to the disease. Two covariates, one which measures the absolute difference between the number of years the patients have suffered from the disease and similarity between two nodes of the onset of the disease, were included in this model. The results indicate that both disease covariates are significant. The positive coefficient for *absdiff(Years suffering from rare disease)* suggests that the greater the difference between the nodes, the higher the propensity for a tie between this two nodes. This is expected since patients who have more experience with the diseases are better positioned to provide advice and information to patients who have a shorter experience. The positive coefficient for the variable *nodematch(Onset)* suggests that patients who have the same onset of the disease are more likely to form a tie. For example, a patient whose disease onset started at the arms is more likely to communicate with another patient with the same onset region. Again, this is expected since we believe that the patients have a predisposition to seek out or reach out to patients with similar disease characteristics as they are most capable of providing relevant and applicable responses.

In Model 3, we examined the demographic variables of age and gender. The coefficient for age difference is negative and significant (-0.34, p<0.001), suggesting that the smaller the age difference between the two patients, the higher the propensity for tie formation. On the other hand, the coefficient for gender similarity is positive and significant (0.08, p<0.001), suggesting that there could be an affinity for patients to respond to other patients of the same gender.

Model 4 is used to test the community effects. We included a measure *absdiff(Member)* which captures the patients´ membership in the online health community (or the number of years elapsed since joining the community). Our results show that the coefficient of the difference in tenure of patients in the community is significant and has effect for the propensity of tie formation, conditional on other network statistics. This finding is in line with previous studies of “general” online communities, where tenure often plays an important role in contribution in groups and online communities (Ancona and Caldwell 1992, Kraut et. al. 2002). This coefficient is negative which suggests that the smaller the difference in tenure between the two nodes, the more likely that a supportive tie between the dyad will form.

In Model 5, the two measures of interest related to location, *nodeifactor(urban)* and *nodeofactor(urban)*, are added. We introduced the higher-order triadic closure term (GWESP) and reciprocity term. This helps to determine whether the observed tendency for homophilic, sender and receiver ties is amplified by the balancing mechanisms of reciprocation and closed triangles, independent of the characteristics of the alter. To control for reciprocity and triadic effects, we added *mutual* and *gwesp* in the models respectively. From the results of model 5, we find that the coefficients for *nodeofactor(urban)* are positive and significant. This implies that the urban patients are more likely to provide support by responding to other patients. More interestingly, we find that *nodeifactor(urban)* is negative and significant, implying that rural patients are more likely to receive support. The structural variables mutuality and triadic closure were positive and significant and we find that after controlling for these higher order structural variables, age and gender homophily effects are no longer significant. The direction and significance of all other variables are similar to those in base models 1-4.

nodeofactor(urban) and *nodeifactor(urban)* measure how connections are made to and from a node, but do not reflect where the information flows from or towards. In Model 6, we use direct measures of information flow across locations: *Urban→ Rural*, *Rural→Rural*, and *Rural→ Urban.* These covariates allow us to examine the structural patterns of supportive ties between urban and rural patients and whether they occur more than expected. The coefficient for *Urban→Rural* is positive and significant. This suggests that *Urban→ Rural* has a greater occurrence than at random and increases the propensity for tie formation. On the other hand, the coefficient for *Rural→Urban* is negative indicating that this structural pattern where rural patients provide support to urban patients occurs less frequently than in randomly generated graphs and there is a decreased propensity for supportive tie formation. Again, reciprocity and triadic closure are positive and significant in this model.

Overall, the results corroborate our hypothesis for sender node and receiver nodes, i.e., there is a not surplus of support from urban to rural patients.

Goodness of fit

Goodness of fit was established using two approaches. First, we explored the plots of the estimated networks to determine how closely they matched the observed networks. Second, we calculated the Akaike´s Information Criterion or AIC (Akaike, 1973) and the Bayes Information Criterion or BIC (Shwartz, 1978). Looking at the differences in the information criterion values for Models 1-6, models 5 and 6 appear to have a better fit than the rest of the models.

To determine if the models generated by ERGM were indeed close to the real behavior in networks, we establish whether the properties of the network that were not explicitly modeled are close to the actual network. We used the conventional approach whereby simulations of the proposed model are compared to the actual network (Goodreau et al. 2008, Hunter et al. 2008). For a given network statistic (such as the indegree), if the simulated model is close to that of the actual network, this implies and provides a greater degree of confidence for the model.

We generated 1000 simulations of random networks for each model and examined how well the models fit the actual network. The simulations determine the extent to which micro-processes represented by a model are capable of reproducing key features of the networks' global structure specifically, the indegree, outdegree, edge-wise, dyad-wise shared partners and geodesic distances. Then we examine where the real network statistics occurs relative to those of simulated networks. Based on the simulated networks, we compare the network statistics. If the models accurately represent obderved information exchanges, the distribution for these two networks should be relatively similar.

Simulation results for the dyadic dependent ERGMs are shown in Figure 3. In each of the goodness of fit plot produced, the solid line represents the actual network while the boxplots show the values of the above four network statistics produced by the simulations. As shown in the figure, the goodness of fit plots fit the original data quite well. The model appears to have slightly under predicted edge-wise shared partners for small values and over predicted for larger vales. Similarly, for geodesic distances, the model appears to have over predicted geodesic distances for those with small number geodesic distances. The other graph level indices were predicted reasonably well.

5.3 Information flow in different thread categories

To address our research question about the characteristics of the threads, we analyzed 6 different networks created by classifying threads into categories suggested in prior work (Graydon et al., 1997; Rutten et al. 2005): (i) symptoms, prognosis and nature of disease; (ii) medication and treatment; (iii) restoration and coping; (iv) disease experiences; (v) treatment experiences; and (vi) emotional support. To classify the threads according to the six different categories of messages, the standard classification procedure was followed through using TagHelper (Rose, n.d.). This procedure entails three steps: developing the classifier, testing and validation, and applying the classifier to the messages.

Threads are categorized automatically using a support vector machine algorithm. The support vector machine (SVM) method is a supervised learning method widely used in classification tasks, and has been shown to be effective in classifying text messages and handling large feature sets to obtain optimum solutions (Burges, 1998). We built six different classifiers using linear SVM with a training set of 500 forum messages using a 10-fold cross validation approach. This training set was obtained by randomly selecting 500 messages from the whole forum dataset. The author and a graduate student were provided definitions of the categories in Table 4 first manually performed categorization of the messages. The inter-rater reliability score was 86%. Each message may be classified in more than one category. This occurs because forum messages, especially longer messages, may fall into more than one category. For the small number of messages that were classified differently, a consensus was reached between the two human coders to decide the final category.

In the validation step, the classifier's accuracy was tested using a subset of the sample not included in the training set. These 100 messages were randomly sampled and independently evaluated by a graduate assistant. The accuracy was derived by the fraction of the total number of messages where the predicted category generated by the classifier is equivalent to that of the category classified by the graduate assistant. Accuracy rate is reported in Table 4, and ranges from 72-97%.

In the last step, the classification was applied to the entire data set using the six separate classifiers for each category built from the previous steps. Because binary classifiers are used, each thread may be classified into more than one category. Although this process takes longer, it preserves the characteristics of messages in the forum where one message could contain different themes and topics.

--INSERT TABLE 4 ABOUT HERE--

The data was analyzed using simple descriptive evidence reported in Table 5. From Table 5a, we can identify which categories of threads created by rural patients induced the smallest ratio of responses from rural patients compared to urban patients. The top three categories were: Disease experiences ranked first, followed by emotional support, and finally restoration and coping tips ranked third. We see that there are more posts by urban users than rural users for all the categories except for research and forum related content. The interest in research indicates that rural users seek information about the disease much more than urban users. This could be because they lack information about the disease as a result of poor medical information and expertise in rural areas.

From results shown in Table 5b, we find evidence that patients suffering from rare disease are likely to seek online support first about information related to medication and treatment, restoration and coping, treatment experiences, nature of disease (prognosis, symptoms and diagnosis), emotional support and then disease experiences. Unlike Girgis et al. (2002), we did not find significant differences in the top most needs of the rare disease patients who reside in urban versus those in rural locations. Both groups sought and posted the most number of threads on topics relating to medication and treatment as well as restoration and coping.

--INSERT TABLE 5 ABOUT HERE--

Table 6a and 6b show the net inflow of support for urban and rural patients. The measure of net inflow is defined as the ratio of incoming messages to outgoing messages. Results in 6a shows that the net inflow of support is higher for rural compared to urban patients. The net inflow is further broken down by source location and results indicate that rural patients consistently receive a greater inflow of support from urban patients compared to rural patients.

--INSERT TABLE 6 ABOUT HERE--

Next, we present the estimates of ERGM models for each of the different types of support exchanged between patients in the online community in Table 7. For the network of information exchanges occurring between threads discussing the nature of disease, prognosis and symptoms (Table 7, Model 1), *Urban→Rural* exchanges was statistically significant. The ERGM estimate indicates that type of tie *Urban→Rural* in the network is a significant predictor of the presence of that supportive tie in the network, when controlling for density and other network covariates.

Similarly, the coefficient for *Urban→Rural* in the networks based on the discussion of treatment experiences (Model 5) and emotional support (Model 6) is also positive and significant. For these two networks, the *Rural→Urban* is negative and statistically significant when controlling for other network covariates. If we compare the coefficients of the *Urban→Rural* ties across the models, we see that the highest coefficient occurs in the first network (nature of disease) followed by treatment experiences, emotional support, disease experiences, restoration and coping and lastly, medication and treatment. *Rural→Rural* occurs most often in support networks discussing about the nature of disease, treatment experience, medication and treatment, restoration and coping and finally emotional support. Comparing the *Rural→Urban* coefficients, we find that the highest coefficient occurs in the network for restoration and coping, followed by disease experiences, medication and treatment, nature of disease, emotional support and finally treatment experiences. We see that most coefficients are negative indicating a decreased propensity for a supportive tie to occur from rural to urban patients.

--INSERT TABLE 7 ABOUT HERE--

6 Conclusion

The accelerating growth in online health communities and robust participation by patients offers the opportunity to positively influence public health. Our study elucidates the dynamics of support offered and received in the interactions within an online health community, highlighting the social value online health communities create by bridging the rural-urban health divide. The findings could assist community agencies and public health facilities in making decisions about how to allocate resources to meet the needs of patients who seek specific assistance and overcome disparities in medical access.

To isolate social value, we modeled the online social support of patients participating in an online health community where nodes in a network represented the patients who are interconnected on multiple dimensions including patient disease characteristics and location characteristics. Using data collected from a popular online health community, we found empirical evidence for our hypothesis that urban patients are the net suppliers of online social support to rural patients. On the whole, it appears that urban patients, who have greater access to medical expertise and information, provide informational support to rural patients by responding to questions related to the nature of disease, disease symptoms and prognosis, after controlling for network characteristics, disease and demographic homophily. In addition to informational support, urban patients provide emotional support to rural patients more than their rural counterparts. To the best of our knowledge, this is the first study to demonstrate social value creation in online health communities.

Interestingly, we do not find significant differences between urban and patient needs in terms of the threads they post. The results indicate that patients in the community who are suffering from a rare disease are equally likely, independent of their location, to post questions and seek content related to medication and treatment information, restoration and coping tips, treatment experiences, nature of disease (prognosis, symptoms and diagnosis), emotional support and disease experiences.

A second key contribution of this paper is to model the supportive ties in online health communities using the ERGM approach. The method we used accounts for network structure and overcomes the major limitation of traditional techniques. To our knowledge, this is also the first paper to model information flows in online health communities as a network using ERGM. This relatively novel technique allows us to analyze the network controlling for structural characteristics, which has been lacking in prior research. As this approach is starting to spread to a multitude of fields, the application of the methodology in this study should generate further interest in this method.

This study has some limitations that need to be acknowledged. First, the demographic data is self-reported, which might suffer from self-reporting biases. Second, as the data is collected from a single community focusing on a rare disease, the generalizability of the findings to other types of online health communities needs to be viewed with caution. Finally, we are unable to test for the actual health benefit of such online support, which we leave to future research.

Figure 1: Network diagram of community

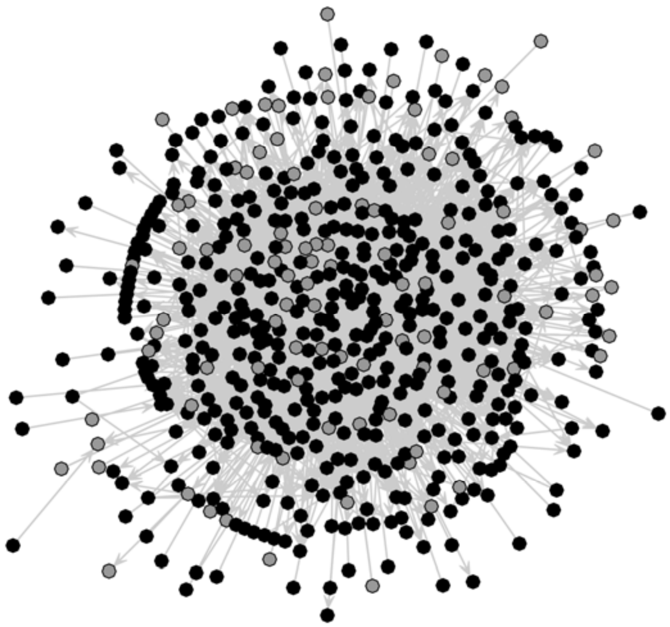


Figure 2a: Degree ratio

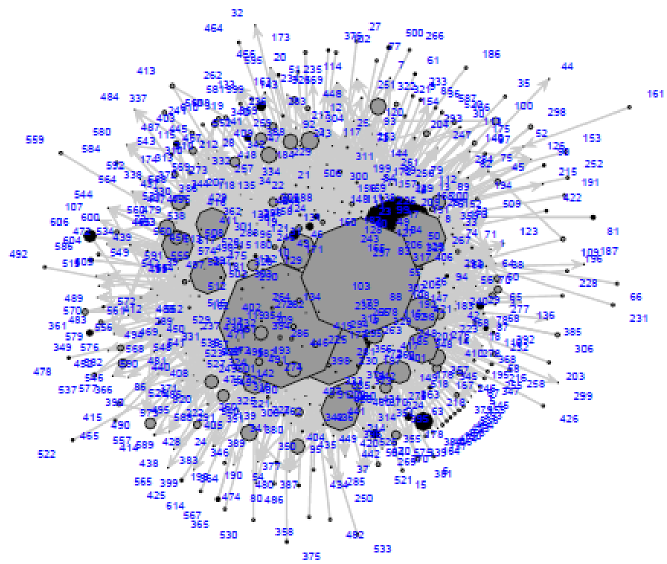


Figure 2b: Inverse of degree ratio

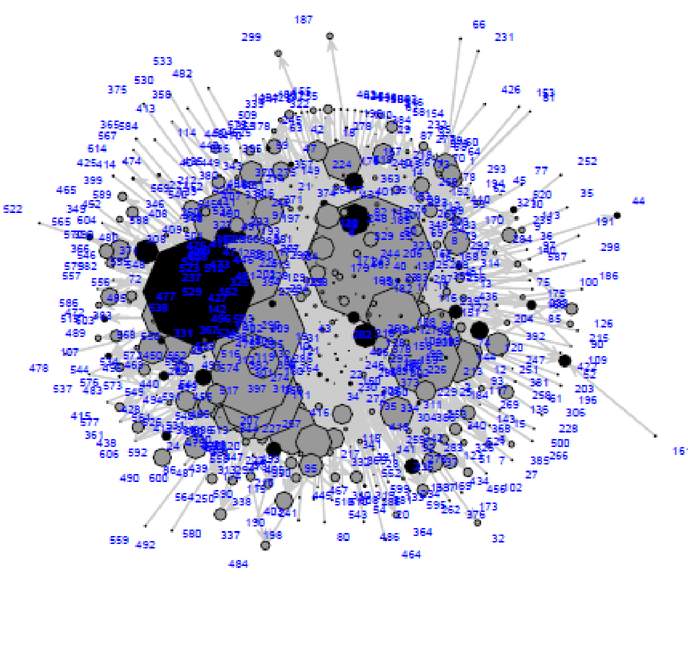


Figure 3: Goodness of Fit Plots

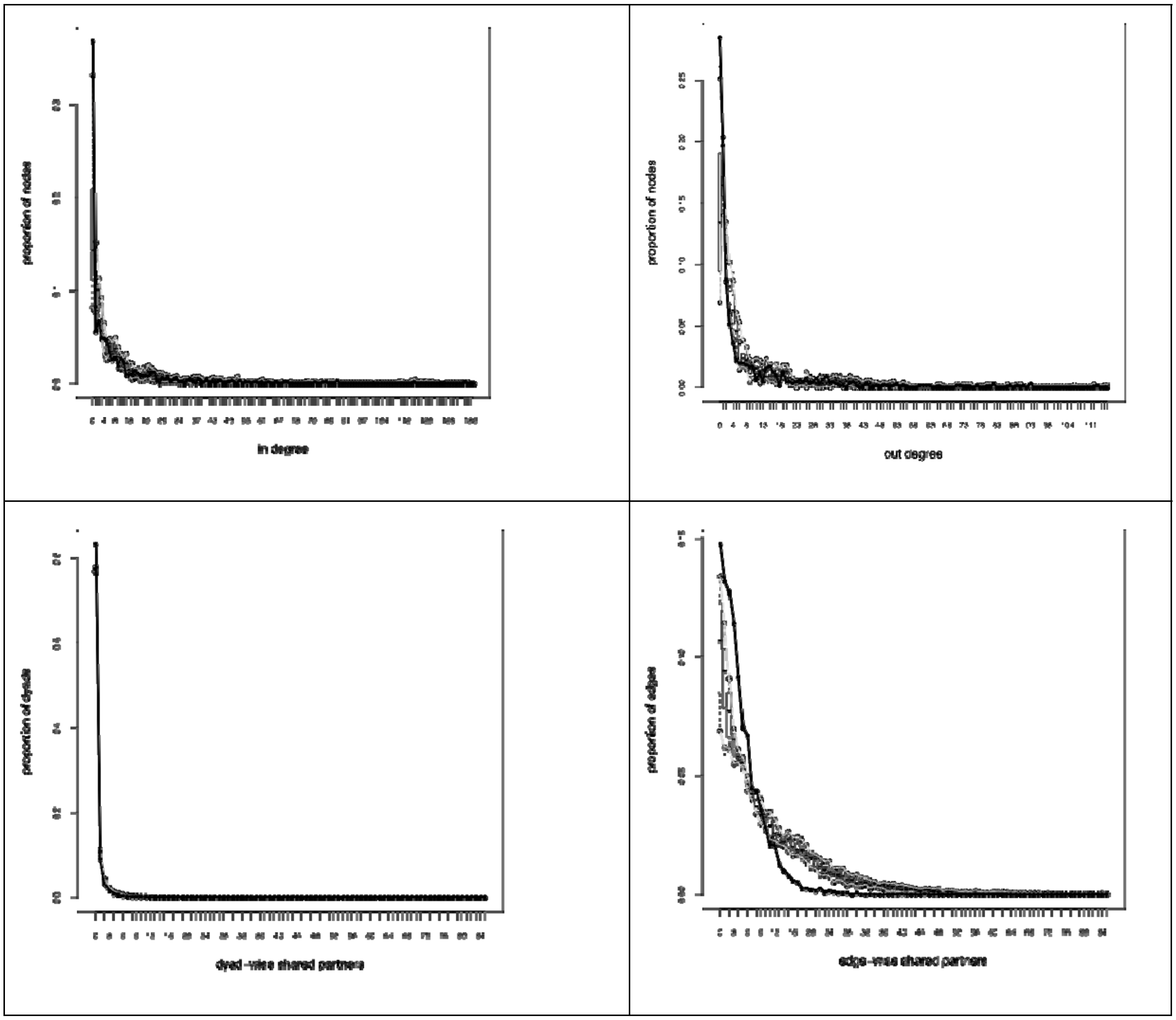


Table 1a: Summary Statistics

Variable	Obs	Median	Mean	S.D.	Min	Max
Demographic Covariates						
Age	638	56	55.33	11.04	16	85
Location	638	1	0.83	0.38	0	1
Disease						
Years suffering from rare disease	638	5	6.26	4.99	1	43
Community						
Membership	638	3	3.56	1.09	1	6

Table 1b: Frequency Distribution

Variable		Frequency
Location		
	Rural	111
	Urban	527
Gender		
	Female	274
	Male	364
Onset area		
	Arms	239
	Bulbar	160
	Legs	212
	Respiratory	27

Table 2: Summary Statistics for Centrality

Variable	Obs	Median	Mean	S.D.	Min	Max
Degree centrality	638	8	61.64	223.04	0	3815
Indegree	638	3	30.82	134.32	0	2528
Outdegree	638	2	30.82	101.45	0	1287

Table 3: Exponential Random Graph Models

Covariates	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Edges	-4.096 <1e-04 ***	-4.332 <1e-04 ***	-3.782 < 1e-04 ***	-3.739 <1e-04 ***	-5.258 <1e-04 ***	-5.229 <1e-04 ***
Disease						
absdiff(Years suffering from rare disease)		0.033 <1e-04 ***			0.022 <1e-04 ***	0.017 <1e-04 ***
nodematch(Onset)		0.202 <1e-04 ***			0.097 <1e-04 ***	0.087 <1e-04 ***
Demographic						
absdiff(Age)			-0.340 < 1e-04 ***		-0.004 0.208	-0.004 0.530
nodematch(Gender)			0.082 0.001 ***		0.007 0.919	-0.031 0.647
Community						
absdiff(Membership)				-0.341 <1e-04 ***	-0.252 <1e-04 ***	-0.257 <1e-04 ***
Balancing mechanisms						
Reciprocity						
Mutual					2.131 <1e-04 ***	2.311 <1e-04 ***
Triadic closure (GWESP)					1.574 <1e-04 ***	1.534 <1e-04 ***
Location effects						
nodeifactor(urban)					-0.093 <1e-04 ***	
nodeofactor(urban)					0.028 <1e-04 ***	
Rural→Rural						0.049 0.714
Urban→Rural						0.051 <1e-04 ***
Rural→Urban						-0.031 <1e-04 ***
AIC	67711	67363	67077	67086	53126	53343
BIC	67722	67395	67110	67108	53235	53463

*** Significant at 1 percent level
** Significant at 5 percent level
+ Significant at 10 percent level

Table 4: Classification accuracy and examples

Category Label	Classification Accuracy (Gu et al., 2008)
Nature of disease, prognosis, symptoms, diagnosis	94%
Medication and treatment	97%
Restoration and coping	86%
Disease experiences	87%
Treatment experiences	86%
Emotional support	72%

Table 5a: Types of replies

Category		Thread Creator Location	
	Replier Location	Rural(0)	Urban(1)
Nature of disease, prognosis, symptoms, diagnosis	0	381	242
	1	434	1347
Medication and treatment	0	472	577
	1	668	3348
Restoration and coping	0	360	566
	1	471	2946
Disease experiences	0	299	308
	1	347	1677
Treatment experiences	0	383	242
	1	436	1347
Emotional support	0	263	337
	1	490	1742

Table 5b: Threads of each type

Category	All	Rank	Rural	Rank	Urban	Rank
Nature of disease, prognosis, symptoms, diagnosis	673	4	174	4	189	4
Medication and treatment	1336	1	248	1	511	1
Restoration and coping	964	2	184	2	385	2
Disease experiences	502	6	106	5	181	6
Treatment experiences	675	3	175	3	189	4
Emotional support	671	5	92	6	259	3

Table 6a: Net Inflow of Support

Category	Net Inflow Rural	Net Inflow Urban
Nature of disease, prognosis, symptoms, diagnosis	1.38	0.89
Medication and treatment	1.09	0.98
Restoration and coping	0.9	1.03
Disease experiences	1.06	0.98
Treatment experiences	1.31	0.89
Emotional support	1.25	0.93

Table 6b: Net Inflow of Support by Location

Category	From	Net Inflow For Rural Patients	Net Inflow For Urban Patients
Nature of disease, prognosis, symptoms, diagnosis	Rural	0.61	0.14
	Urban	0.70	0.76
Medication and treatment	Rural	0.45	0.14
	Urban	0.64	0.83
Restoration and coping	Rural	0.39	0.17
	Urban	0.51	0.86
Disease experiences	Rural	0.49	0.15
	Urban	0.57	0.83
Treatment experiences	Rural	0.61	0.14
	Urban	0.70	0.76
Emotional support	Rural	0.44	0.15
	Urban	0.82	0.78

Table 7: Exponential Random Graph Model to Explain Each Thread Type

	Model 1 Nature of disease	Model 2 Medication and treatment	Model 3 Restoration and coping	Model 4 Disease experiences	Model 5 Treatment experiences	Model 6 Emotional support
Edges	-6.077 < 1e-04 ***	-5.758 <1e-04 ***	-5.848 < 1e-04 ***	-6.112 < 1e-04 ***	-6.072 < 1e-04 ***	-5.886 < 1e-04 ***
Absdiff(age)	-0.0134 0.0001***	-0.006 0.073+	-0.010 0.0009 ***	-0.003 0.473	-0.014 0.002 ***	-0.013 0.0041***
Nodematch(gender)	0.079 0.249	0.065 0.241	0.076 0.228	0.082 0.199	0.108 0.186	-0.045 0.513
Rural→Rural	0.228 0.189	0.139 0.453	0.138 0.423	0.171 0.342	0.222 0.212	0.0501 0.806
Urban→Rural	0.307 0.0004 ***	-0.035 0.689	0.050 0.636	0.128 0.160	0.196 0.031 ***	0.196 0.030** *
Rural→Urban	-0.093 0.327	-0.068 0.277	0.012 0.849	-0.018 0.860	-0.254 0.022***	-0.194 0.026 ***
Absdiff(alsyrs)	0.027 < 1e-04 ***	0.023 <1e-04 ***	0.018 < 1e-04 ***	0.021 < 1e-04 ***	0.030 < 1e-04 ***	0.016 < 1e-04 ***
Nodematch(onset of disease)	-0.018 0.408	0.082 <1e-04 ***	0.133 < 1e-04 ***	-0.052 0.002 **	-0.008 0.644	0.133 < 1e-04 ***
Absdiff(membership)	-0.411 < 1e-04 ***	-0.303 <1e-04 ***	-0.357 < 1e-04 ***	-0.453 < 1e-04 ***	-0.401 < 1e-04 ***	-0.372 < 1e-04 ***
Mutual	0.459 0.003 ***	1.193 <1e-04 ***	1.358 < 1e-04 ***	1.042 < 1e-04 ***	0.447 0.005**	0.920 < 1e-04 ***
Gwesp	2.505 < 1e-04 ***	1.926 <1e-04 ***	2.099 < 1e-04 ***	2.457 < 1e-04 ***	2.480 < 1e-04 ***	2.362 < 1e-04 ***

*** Significant at 1 percent level
** Significant at 5 percent level
+ Significant at 10 percent level

Conclusion

The overarching goal of this dissertation was to shed light on the mechanisms and processes through which health information technology generates value for organizations and individuals. This goal was addressed in two separate studies in distinct contexts: the traditional setting of a hospital, and the emerging context of online health communities.

The first essay develops a theory for appropriating HIT value in the traditional hospital setting by providing an endogenous view of technology and routines. This is the first study to propose a grounded theory of adaptive routinization. The lens is unique and highly relevant: it offers a new way for managers to understand the process of HIT implementation and increase the chance of a successful implementation. It also demonstrates how changes to routines can be modeled using network diagrams (Pentland, 2011). Future studies can build upon this theory and approach to model routines so as to elaborate the underlying mechanisms that occur when HIT is introduced in a healthcare organization. The findings from this study allow practitioners to enhance their chances of successful HIT implementation by delineating the mechanisms that will steer a positive outcome. The study was motivated by the theoretical and practical need for understanding the equivocal findings in prior research related to the value of HIT. It advances theory by highlighting the co-evolutionary mechanisms between technology and routines, which is lacking in the IS literature.

The second essay provides insights into another form of HIT, online health communities. This study examined the potential of online communities in alleviating problems related to health disparity among rural and urban patients. Extant studies have not examined the patterns and dynamics of support between rural and urban patients; a gap that the study directly addresses. . It also contributes to the literature by being the first study to examine the research question using exponential random graph methods. Findings indicate that a net inflow of social support from urban to rural patients is ocurring, demonstrating how social value can be appropriated from online health communities.

Obtaining HIT value is a complex and difficult process and understanding how HIT value can be appropriated warrants much attention at this stage. The issue of HIT value is of central importance for policy makers who allocate resources and establish the legislative infrastructure for HIT implementation, and for providers and patients who are directly affected by the use and outcomes of health IT. This dissertation seeks to answer some of the important questions raised by the digital transformation of healthcare. It is hoped that its findings will provide a building block for future work in the area of HIT.

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