PROJECTING TRAJECTORIES OF FUNCTIONAL USE FOR A NEW TECHNOLOGY: THE ELECTRONIC ICU

DISSERTATION

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By

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ABSTRACT

There are an increasing number of new technological innovations emerging and being fielded in the market, especially medical technologies. Studies of these new technologies should consider trajectories of change and adaptation as new systems and capabilities are introduced and mature. Within the literature is a variety of technology adoption, evolution and radical change models; one widely cited view of technology adoption is Rogers’ diffusion of innovation, which has been used to empirically examine attempts to inject new technologies into various domains.

Rogers’ diffusion of innovation accounts for success stories of technology adoption; however, it is limited for technologies that are rejected by intended users, require significant tailoring, or are used for unexpected functions. The proposed dissertation research takes a cognitive systems engineering perspective to reinvigorate the study of the impact of new technology in complex, socio-technical settings, by focusing on the intersections of the domain, artifacts (e.g. tools and technologies), and practitioners. A case study of a specific new technology was conducted using a triangulation of ethnographic methods—observations, interviews, and log analysis. The emerging telemedicine example studied in this research is the electronic intensive care unit (e-ICU). The e-ICU was implemented in a single hospital in 2000; it was not subsequently expanded to other hospital systems until years later and since then has seen
increased usage around hospital systems. The study summarizes the current e-ICU functions into three groups: access to expertise, anomaly response, and sensemaking. Additionally, intervention logs where the e-ICU nurses write down every time a discourse occurs between the e-ICU and ICU were examined. The intervention log analysis lends support to the hypothesis that these functions and additional functions of the e-ICU are changing over time. Finally, the interviews provide a survey of additional functions that other e-ICUs across the country.

Previous research utilizes these methods to identify patterns in how expert practitioners interact with computerized support to achieve domain-specific objectives, making no projections about potential trajectories of adaptation through use that may occur over the longer term. This research is novel in that the findings form the foundation of a proposed, expanded, theoretical framework of trajectories and indicators of technology change.

This research is anticipated to have theoretical as well as applied contributions. First, an enhanced theoretical framework should better enable companies to predict the impacts of new technologies in emerging markets by providing possible trajectories and associated indicators. Thus, these projections may be further explored in future research as to how technology may be steered into more productive trajectories, and how to mitigate the negative “side effects” associated with particular trajectories. The research suggests that the ability to project possible trajectories in order to aid in selecting among alternatives and managing post-conditions of change can be done based on the pattern
base built up through cognitive systems engineering and the proposed theoretical framework.
Dedicated to all my family and friends

who have improved my trajectories
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>v</td>
</tr>
<tr>
<td>ACKNOWLEDGMENT</td>
<td>vi</td>
</tr>
<tr>
<td>VITA</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xiii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xiv</td>
</tr>
<tr>
<td>CHAPTERS:</td>
<td></td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Technology Change</td>
<td>2</td>
</tr>
<tr>
<td>1.1.1 Technology adoption</td>
<td>4</td>
</tr>
<tr>
<td>1.1.2 Implementation Consequences</td>
<td>11</td>
</tr>
<tr>
<td>1.1.3 Evolutionary Technology Transformation</td>
<td>16</td>
</tr>
<tr>
<td>1.1.4 Radically Different Technology</td>
<td>21</td>
</tr>
<tr>
<td>1.2 Cognitive Systems Engineering</td>
<td>24</td>
</tr>
<tr>
<td>1.3 Description of the Electronic ICU (e-ICU)</td>
<td>28</td>
</tr>
<tr>
<td>1.4 Current study</td>
<td>35</td>
</tr>
<tr>
<td>2. METHOD</td>
<td>37</td>
</tr>
<tr>
<td>2.1 Pilot interviews and observations</td>
<td>38</td>
</tr>
<tr>
<td>2.2 Cognitive Task Analysis</td>
<td>39</td>
</tr>
<tr>
<td>2.2.1 Participants</td>
<td>39</td>
</tr>
<tr>
<td>2.2.2 Procedure</td>
<td>39</td>
</tr>
<tr>
<td>2.3 Log Data Analysis</td>
<td>41</td>
</tr>
<tr>
<td>2.3.1 Procedure</td>
<td>41</td>
</tr>
<tr>
<td>2.4 E-ICU Interviews</td>
<td>43</td>
</tr>
<tr>
<td>2.4.1 Participants</td>
<td>43</td>
</tr>
<tr>
<td>2.4.2 Materials</td>
<td>44</td>
</tr>
<tr>
<td>2.4.3 Procedure</td>
<td>44</td>
</tr>
</tbody>
</table>
3. CURRENT e-ICU SYSTEM ANALYSIS ................................................................. 46
   3.1 Cognitive Task Analysis .............................................................................. 46
      3.1.1 Anomaly Response ............................................................................... 47
      3.1.2 Access to Specialized Expertise .......................................................... 49
      3.1.3 Sensemaking ....................................................................................... 51
      3.1.4 Summary ............................................................................................ 52
   3.2 Intervention Log Data Analysis Results ....................................................... 52
   3.3 E-ICU Interview Results ............................................................................ 56

4. POTENTIAL TRAJECTORIES OF TECHNOLOGY CHANGE ..................... 62
   4.1 Archetypal Patterns and Projected Trajectories .......................................... 65
      4.1.1 Adaptability and Resilience ................................................................. 65
      4.1.2 Coordination for Collaboration ........................................................... 69
      4.1.3 Coping with complexity ..................................................................... 72
   4.2 Discussion of archetypal patterns ............................................................... 73
   4.3 Applying Archetypal Patterns to Intervention Log Data ............................. 78
   4.4 Proposed Framework ................................................................................ 81
   4.5 Conclusion ................................................................................................ 92

REFERENCES ...................................................................................................... 93

APPENDIX .......................................................................................................... 104
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Codes for e-ICU Functions for Logged Interventions</td>
<td>43</td>
</tr>
<tr>
<td>3.1</td>
<td>Participant responses to a question about the e-ICU’s most useful characteristic</td>
<td>58</td>
</tr>
<tr>
<td>3.2</td>
<td>Participant responses to a question about the e-ICU’s least useful characteristic</td>
<td>59</td>
</tr>
<tr>
<td>3.3</td>
<td>Participant responses to a question about the e-ICU’s implementation surprises</td>
<td>61</td>
</tr>
<tr>
<td>4.1</td>
<td>Preliminary potential trajectory outcomes</td>
<td>64</td>
</tr>
<tr>
<td>4.2</td>
<td>Participant responses to a question about the e-ICU’s future potential</td>
<td>75</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure

1.1 Technology change cycle................................................................. 4
1.2 S-curve of technology adoption.................................................. 6
1.3 Representative view of e-ICU workstation.................................. 31
1.4 Picture of e-ICU facility layout.................................................... 34
3.1 Log data percentages for categories at three different times........ 54
4.1 Hypothetical example of how e-ICU functions change over time... 79
4.2 Linked expansion and constrictions of technology change.......... 85
4.3 Notional example of normalization of the ICU to e-ICU system transition......................................................... 87
4.4 Example of linkages to other units within the hospital system..... 90
CHAPTER 1

INTRODUCTION

In highly dynamic environments, technological advances occur rapidly and in exceedingly competitive markets. Within these markets it is vital to discover promising future technological applications. This proposal looks at a specific emergent technology, the electronic intensive care unit (e-ICU), as a test case in which to study the impact of this newer technology on medicine. The e-ICU is a remotely located facility that monitors intensive care patients in addition to the traditional bedside care. In addition to looking at the current functions of the e-ICU, the test case also serves a more general purpose as a platform in which to explore theoretical directions for indicators of change and expected trajectories of new technologies.

Currently a number of models of technology forecasting and change exist. This research will present a potential theoretical example of technology change using principles of cognitive systems engineering (CSE) to identify patterns in how expert practitioners interact with computerized support to achieve domain-specific objectives, and how these interactions change over time. This approach draws on principles of system design using a methodological approach where a triad of aspects is considered: humans, machines, and work. Prior CSE studies of operators in
complex fields of practice have focused on points of technology change, and these studies have revealed types of discontinuities between the anticipated and the actual effects on human performance following the introduction of new devices and systems (Woods and Dekker, 2000; Woods and Hollnagel, 2006).

This study reviews the technology forecasting literature and selected cognitive systems engineering literature in the analysis of a telemedicine technology, the e-ICU. A novel theoretical framework of trajectories consisting of linked expansions and constrictions is presented. Additionally, indicators of technology change were generated using data from the e-ICU produced from this research. The research introduced the current status of the test case and described the studied setting where the observations and log analysis took place. This theoretical framework is expected to be usable not only in the medical field, which is seeing an increasing infusion of technology, but other areas such as aviation and military domains as well.

1.1 Technology Change

In technology forecasting change, multiple conceptual models exist that encompass a vast array of issues, both positive and negative, surrounding technology forecasting. There are four types of conceptual models that examine how technology and its subsequent use change over time (Figure 1.1). The first type of models focuses on forecasting technology adoption and is associated with the trial period of a potential technological innovation, where one or two individuals or companies experiment with a new technology.
The second type of conceptual models focuses on initial widespread use of a new technology and the subsequent side effects of implementation. These models focus on changes to how tasks are accomplished and potential surprising and unexpected consequences after the initial diffusion in which the technology is further widespread but initial implementation and learning is ongoing. Additionally, the implementation consequences that occur after preliminary deployment could be the result of potential instability of the technology.

The third type of conceptual models focuses on evolutionary technology changes subsequent to being fielded and the initial side effects of implementation have been revealed. The technology is considered to be more stable and new organizational pressures begin to play a larger role in how the technology is used.

Finally, the fourth type of conceptual models focuses on the next new technology, which would be considered completely different from one already in place. This is a long-term phase, in which new technology will be considered and even potentially fielded thus illuminating the cyclical nature of these four congruent phases. Each of these points in the technology forecasting cycle will be briefly discussed in turn.
1.1.1 Technology adoption.

In the technology adoption phase of a predicted new technology only innovators or early adopters undertake a new technology that may even be a reduced functionality version. For example, the electronic intensive care unit (e-ICU) was
first implemented by a single hospital, and was the only one in existence for two years. This type of characterization where the focus is on asynchronous implementation is best illustrated by Rogers’ (1962) diffusion of innovation. In this model the impact of a new technology is conceptualized as stages of diffusion by communication and spreading use through a population (See Figure 1). This widely cited representation depicts the diffusion process plotted as the cumulative penetration of an innovation over time, which is an “S-curve” for technology adoption (Rogers, 1962). The slope of the S curve represents how quickly a population adopts an innovation. Characteristics of groups have been identified, such as distinguishing the first to adopt (“innovators”) and last to adopt (“laggards”) by educational level and propensity to accept risk. Since new technologies can be initiated before the full adoption cycle has completed, new S-curves can be triggered and the multiple curves interact.
There are a number of limitations to the S-curve model, because it was empirically derived from relatively simple domains, such as agrarian methods for food production, and there is a wider base of empirical observations about the patterns of reverberations following attempts to inject new technology (e.g., Barley and Orr, 1997). First, the S-curve model does not consider or include alternative trajectories to adopt/not adopt. Second, it was not designed to accommodate complex, multi-function, semi-automated, computationally intensive technologies. As a result, the model does not capture the empirical results where only portions of new devices or systems may be adopted, as significant tailoring through use will occur over time. Third, the model implicitly assumes a self-paced world in that there are no deadlines.
or other landmark events that influence adoption/rejection decisions. Fourth, it is assumed that the role of adopters remains largely unchanged following adoption of the innovation, whereas observations at points of technology change have identified significant changes in roles and interactions over roles. Finally, it is assumed that the innovation has no significant interactions with existing tools or practices; for example, innovations that more closely match current work practices might be more likely to be adopted. Similarly, there might be positive or negative “side effects” of change on interacting technologies, tasks, and risks. Overall, the S-curve model assumes a process of adoption whereas the ethnographic research base finds a process of adaptation that changes what people do, how they do it, the vulnerabilities for failure, and why they want to engage in these activities (i.e., goals change).

The S-curve adoption model is an oversimplified view of technology change. For example, the S-curve adoption model cannot explain the notably high failure rate for new software. For information technology in general, including the healthcare sector, in a 1998 survey by the Standish Group, the overall success rate for completing software projects was found to be 26%. For 46% of software projects, it was completed and operational but over budget, delayed, and delivered fewer features and functions than originally contracted. An example of this is the Denver baggage system, which delayed the opening of the new Denver airport and cost an estimated $600 million for 10 years of use, was abandoned in favor of manual baggage handling. Finally, 28% of software projects were canceled prior to completion. In addition, there are a number of software intensive systems that reach completion and
are fielded yet, prove to be ineffective. In healthcare, a recent systematic review found that, out of 97 randomized controlled trials, only 62 (64%) of computerized clinical decision support systems improved practitioner performance (Garg et al., 2005).

Similarly, traditional epidemiological models have been modified to model the spread of ideas (Bettencourt, Cintron-Arias, Kaiser, & Castillo-Chavez, 2006). The authors explored various numbers of parameters traditionally used in epidemiological models in regression models for the best fit for the spread of a physics innovation. In this case the focus was on person-to-person spread, which is highly correlated to a traditional epidemiological model considering that most disease is spread through human contact. The type of parameters revolved mainly around categories of people and is similar to Rogers’ diffusion of innovation categories. For example, the test case of the model included skeptics, which would be akin to Rogers’ use of the laggards. This model has additional parameters that take into account time to learn the new innovation, amount of exposure to technology and resistance to adoption. While building off of an epidemiological model may have advantages over Rogers’ diffusion of innovation it still has many of the same issues in that it is an oversimplified view of technology change, fails to accurately represent complex socio-technical processes, and considers only adopted technologies rather than incorporating those that fail.

Another model that focuses on adoption that has been researched previously is the technology acceptance model. Technology acceptance research examines
technology of interest using surveys that measure perceived usefulness and ease-of-use by the intended user (Davis, Bagozzi, & Warshaw, 1989; Mathieson, 1991; Taylor & Todd, 1995). The perceived ease of use is the participant’s perception of how effortful a new technology will be to use, whereas perceived usefulness is the participant’s perception of how the technology would enhance job performance. The technology acceptance model focuses on technology adoption, but approaches it from a user-centric position. This model assumes that the end-user is the individual (or collection of individuals) that makes purchasing decisions, which may not always be the case. Also, while a technology may be highly accepted by those surveyed it might not be feasible or cost effect to implement. Finally, the survey fails to take into account the complexity and nuances of integrating a new technology into a complex socio-technical system.

More recently, the technology acceptance model was explored as a predictive indicator of medication process violations. Using the technology acceptance survey, researchers examined three medication administration protocols for self-reported violations or working around the protocol (Aper et al, 2007). These were regressed on a subset of the technology acceptance survey questions, where the protocols perceived as more difficult and less useful were hypothesized to be predictive of more deviations from the protocol. This was not the case as the technology acceptance questions failed to consistently predict violations (Alper et al, 2007). The results of this study may be an artifact of the self-report measure and nurse’s desire to avoid reporting something that may have negative repercussions for them. Finally, using
the technology acceptance model to examine the usefulness of a specific protocol rather than a technology may be limited because of the need to translate it into a process model rather than just a technology.

Rogers’ diffusion of innovation and others focusing on adoption have largely been explored (e.g. Diffusion of Innovations book cited 13769 times according to Google scholar). Additionally, as stated above there are a number of limitations to diffusion models that lead this research to consider other models of technology change rather than just whether or not a technology is adopted. The emphasis on the adoption of technology rather than the adaptation of technology is incomplete. As soon as a technology is introduced the users and the other resources that it is coupled with in the system adapt it. For example, the banking industry introduced ATMs as a new technology, into its already existing system. The ATMs were adapted to interface with each bank’s software systems, so that users did not receive more money from the ATM than their existing account held, and to register when and how much money was withdrawn. Further, some ATMs have been modified to accept deposits rather than just dispense money. None of the functions and constraints would be considered when just examining the adoption of ATMs. Adoption is seen as finite, whereas the rest of the models discussed below will focus much more on developing models that describe or predict what will happen after a technology has been adopted, thus focusing of subsequent adaptation of a technology as an integrated part of a system.
Forecasting technology adoption is not the focus of this current research especially considering that it was conducted in facilities where the technology had been previously implemented. The telemedicine technology examined in this research is currently utilized at the facility where observations took place for a minimum of eight months at the onset of the study and had been previously adopted at numerous other sites around the country.

1.1.2 Surprising Consequences.

Rather than forecasting whether or not a technology will be adopted, this section describes models that examine and forecast the results of fielding a technology as an experiment. Plans about how a technology is to be implemented and used are viewed as guides where deviations are to be expected rather than blueprints where deviations are seen as a sign of failure (Suchman, 1987). When a technology change takes place there are multiple reverberations throughout the field of practice that are unintended side effects in the system. Given that the actual impact of the implementation of a new technology typically creates unanticipated and potentially counterproductive surprises, users develop strategies that tailor the technology to meet their needs in a rational way (Woods & Dekker, 2000).

Practitioners adapt to the given constraints and opportunities that a current system provides for them, when a new technology is introduced those constraints and opportunities change. At best this re-design of the work will adapt in order to provide additional support where cognitively demanding situations arise, as well as to meet the demands of tasks to be performed (Winograd & Flores, 1986). This pattern of
technological change reveals a transformation subsequent to the introduction of a new
technology that alters people’s roles in terms of cognitive and task complexity, what
is routine and exceptional, goal trade-offs, and paths to both failure and success
(Carroll & Rosson, 1992; Sarter, Woods, & Billings, 1997; Winograd & Flores,
1986).

In general these models attempt to predict the transformations and kinds of
strategies that practitioners will develop to cope with the complexity of new
technology. Additionally, practitioners are also under pressure for accomplishing
work in the face of efficiency, performance and temporal demands where it is vital to
the organization to anticipate where error and system failure could conceivably
emerge (Corker, 2000; Rasmussen, 2000; Woods, Christoffersen, & Tinapple, 2000).
Thus the challenge is to create meaningful artifacts that would provide hypotheses
about what would be useful to practitioners and facilitate understanding and expertise
while minimizing potential negative consequences prior to implementation.

These types of unintended consequences can readily be observed in the health
care field where medical information technologies are increasing being implemented.
Recent studies explored the unintended side effects after the implementation of
computerized provider order entry (CPOE) systems. The CPOE system is largely
considered to be the solution to medication order errors, and in studies, a reduction in
adverse drug events have been found (Bates et al, 1998; Feied, Smith, Handler,
Gillam, & Pietrzak, 2004). However, recent studies suggest that this may not be the
case when considering the CPOE system in the context of an integrated system rather
than focusing just on single factor, adverse drug events (Ash, Berg, & Colera, 2004; Berger & Kichak, 2004). For example, Koppel et al (2005) reported that the CPOE system observed actually facilitated 22 types of medication error risks. Perhaps even more revealing is a mortality study that found an increase in mortality rates after a CPOE system was implemented when compared with pre-CPOE mortality rates for a pediatric hospital when the patient was admitted via interfacility transport (Han et al., 2005). Researchers contributed this unexpected increase, in part, due to a delay in the ability of the staff to order patient therapies prior to the patient’s arrival and potentially reduced staffing during patient critical periods in order to facilitate patient needs through the system. In sum, these studies caution the adoption of a CPOE system as not having the intended benefits, especially when examining how the system is actually used and barriers to that use. These studies indicate retrospective accounts and pre / post-technology implementation investigations reveal that task and goal changes do occur, but none of these address a prediction of what the unintended effects will be a priori.

There are a number of models that explore this envisioned world problem or task-artifact cycle where there are unintended consequences of technology change subsequent to implementation (Carroll & Rosson, 1992; Woods & Dekker, 2000). There are functional models that identify the demands and how the fundamental process works in an effort to make explicit how these may be satisfied via cognitive agents or strategies (Roth and Mumaw, 1995).
Conversely, there are a number of techniques that use scenarios as an approach to predict the patterns of change when a new technology is implemented rather than focus on fundamental requirements. One such technique examines the technology artifacts, such as prototypes, that have emerged as a way to anticipate the effects on a system of a new technology. These prototypes, when utilized for a scenario that explores the system demands by those in the field of practice, can reveal possible future operational concepts (Carroll, 2000).

Similarly, Dekker (1996) developed the future incident technique, which builds on the above method of predicting process change when a new technology is introduced using scenarios. Using an envisioned world paradigm of how the system will operate with a new technology, this technique develops a scenario that stretches this new system to its limits embedding a vulnerability or challenge in the field of practice that would create a failure or near miss. Not only does this require knowledge of what will challenge the competence envelope, but also a knowledge of classic design errors (Dekker, 1996).

The above models forecast unintended consequences subsequent to technology introduction, where the focus is on how the whole system is changed and the reverberations that occur. The current study, however, is examining more long-range changes that occur over time as a new technology becomes integrated within a system. The telemedicine example that will be explored here had been in place for a minimum of eight months and was not in danger of becoming extinct or being removed. The unintended consequences of implementation could have been studied
retrospectively via the interviews, but not all participants were involved at the telemedicine inception and the accuracy of recall of events may be questionable (Loftus, 1991). Additionally, in order to accurately assess this, researchers would want to focus on the traditional ICU and the unintended side effects that occurred as a result of the implementation of the new technology. This was not the focus of the current research.

Conversely, from the organizational management perspective, the improvisational model of change management, while more descriptive in nature, bridges the initial implementation consequences with more long term technological change management. Traditionally, the view of an organizational approach to technological change was viewed as a three-stage model: preparing for the change, implementing the change, and regaining stability as quickly as possible (Lewin, 1952). This view is more simplistic and dissonant than what actually occurs when a complex, open-ended and customizable technology is introduced into a system. The improvisational model for managing change attempts to account for unanticipated side effects by creating a more iterative model of change management (Orlikowski & Hofman, 1997).

The improvisation model assumes that the implementation of a new technology is the starting point of an ongoing process rather than a discrete event that cannot be fully anticipated prior to implementation. Additionally, the model suggests that there are three types of change: anticipated, emergent and opportunity-based (Orlikowski & Hofman, 1997). Anticipated change is the technology uses known
prior to implementation and planned for ahead of time, whereas emergent changes are those that are realized without prior planning. Finally, opportunity-based changes are changes that are realized after implementation and purposefully introduced during the change process. Researchers used this model to describe a case study of a company as it is introduced and subsequently adapted the use of a groupware technology over a period of two years (Orlikowski & Hofman, 1997).

The improvisation model of technology change approaches technology implementation from more of a blunt-end or management perspective. None of the other models approach technology change this way; however, this model is descriptive rather than predictive. The authors’ case study supports their assertion that change can be categorized, but there is no a priori exploration of what those changes might be.

1.1.3 Co-evolving Technology Transformation.

This section examines technology change as a long-term co-evolve system where change continues to occur post-implementation, especially as the technology moves from novel to routine. The change here transforms the nature of work that the system was implemented to complete. There are a number of models that view technology forecasting from both evolutionary and foraging theories adapted from the biological sciences.

One such model that has applied evolutionary theories in the context of physical systems and business trends, and more recently technology forecasting, is the Theory of Inventive Problem Solving (TRIZ). TRIZ posits that there are a
number of generic technology evolutionary trends that can predict where technological evolution will migrate when there are no recognizable solutions (Orloff, 2006). In the past, TRIZ has been applied to a wide variety of technical and business systems, where researchers have utilized 30 to 40 of the evolutionary trends to characterize evolutionary potential, such as ball bearing systems or glass plate manufacturing (Altshuller, 1996; Mann, 2003).

More recently, TRIZ principles were used to identify a number of generic evolution steps, which support movement towards realizing future development opportunities and constraints of machines, procedures, or techniques (Mann, 2003). The objective of this forecasting technique is to select the most promising technological evolutionary scenario out of a set of scenarios developed during the process (Zlotin & Zusman, 2002). Future system development ideas developed using the TRIZ process, start by describing the current situation, which includes examining the system functions and how those functions are accomplished, as well as relationships among them. In turn, these functions are further explored using the patterns to examine possible future realizations that could occur. TRIZ posits eight patterns based on previous research on evolutionary trends of how technological systems develop which are:

1) Technology follows a life cycle of birth, growth, maturity, decline
2) Increasing ideality
3) Uneven development of subsystems resulting in contradictions
4) Increasing dynamism and controllability
5) Increasing complexity, followed by simplicity through integration

6) Matching and mismatching of parts

7) Transition from macrosystems to microsystems using energy fields to achieve better performance or control

8) Decreasing human involvement with increasing automation (Orloff, 2006).

These trends along with surveys and simulations form the basis for the forecasting model using the TRIZ framework.

There are a number of limitations to the TRIZ model, especially when considering technology forecasting. The number of potential trends that TRIZ utilizes in its model, which depending on the research may be deemed irrelevant, is less than parsimonious and may create confusion and add complexity. Additionally, the focus has typically been in physical system components or from the perspective of business management where an ideal end-state can be realized. However, this research is focused on an integrated technology system changes how the work is completed and what work to do, such that there may be a shift in the e-ICU focus from monitoring patients’ real time vitals and anomalies, to monitoring for best practice adherence. This shift in goal prioritization is not captured by the TRIZ notion of evolutionary potential. The ideal end-state for this type of system is most likely unknown, due to the fact that shifting goals and trade-offs change the nature of the work to be completed, which is unlike physical systems where the goal of a bearing system component is always going to be to facilitate movement of parts with minimal friction. Additionally, it forecasts a change in the technology but the
specifics of how that change might occur or what that change might be is not projected in TRIZ. Finally, there is some question of reliability and an inability to capture the important role that social interaction plays.

Besides evolutionary theory researchers have utilized foraging theory to study technology systems (Garrett, 2007). Traditional optimal foraging theory is an outcome based on a cost-benefit analysis in which there are three types of assumptions: a decision choosing among multiple choices, a measure with which to evaluate choices and constraints (Stephens and Krebs, 1986). This theory suggests that foraging behavior has evolved to optimize the ratio of energy intake to energy expenditure. Optimal foraging theory has been modified to include not only an individual’s foraging behavior, but to examine that behavior in a social context where others are included in analysis, or social foraging theory (Giraldeau & Caraco, 2000).

Garrett, Caldwell, and Ebright (2006) adapted this concept of optimal foraging theory to the world of health care by focusing on how trade-offs, like goal conflicts, learning, and group settings change the nature of foraging. This culminated in a reclassification of types of foraging that highlight the importance of timeliness in the health care setting. Additionally, the reclassification highlights the event driven nature of health care in order to maximize gains and describes how a system is adaptive over time.

The researchers examined the timeliness of foraging on a continuum from proactive to reactive. Proactive foraging simply means preparing for a future event in terms of people, physical objects, environment, and information prior to event
occurrence while reactive foraging looks at how soon after an event additional resources are requested. The challenges to being proactive in foraging are knowing when an event is about to occur, an event is known but the timing is not known, or the event presents itself in unanticipated ways (Garrett, Caldwell, & Ebright, 2006). While not actually predictive in nature, this study does lend some credence to where a technology might be seen as useful and improve performance in settings where varying workload exists.

Another model that is based on an analysis of three industries over time examines how a new dominant technological product or process emerges. Anderson and Tushman (1990) developed a cyclical model of technological change that focuses on technological discontinuities. Technological discontinuities are defined as industry innovations where there is a marked increase in the performance to cost ratio. The authors posit that there are technological discontinuities that are either competence enhancing or competence destroying technological discontinuities. Competence enhancing discontinuities are those that build on the original technology further exploiting and improving it, such as the addition of different camera technology to render high definition television compared to traditional television. Competence destroying discontinuities are those that require a different knowledge set by the producer and make the original technology extinct, like the replacement of mechanical watches with quartz watches. The technological discontinuities are followed by long periods of incremental change in variation, selection and retention of technologies and practitioners (Anderson & Tushman, 1990).
In each of the three industries, cement, glass and minicomputer, experienced a time of upheaval where many ideas emerged as well as a new winner, which is not the same as what first created the discontinuity. It should be noted that in this model the dominant designs lag behind the industry’s technical frontier, because progress occurs more slowly when sociocultural constraints and acceptance are required than when considering just technology. Finally, this cycle repeats itself over time. This model is limited in that only manufacturing industries were surveyed, which may not be generalized to other industries. Additionally, this model does not distinguish between potential innovations that achieve success and those that do not. In some respects this model bridges the evolutionary technology transformation with the next set of model, radically different technology, especially when considering competence destroying discontinuities.

The above models forecast how a technology could be slightly modified while still in use and maintain stability. Here the focus is on how the technology comes to be used and exploited by both sharp-end and blunt-end practitioners as new pressures emerge. This would also include migration over time to adapt to new settings or new goals and priorities. The final section of the technology forecasting literature is about predicting the next new technology.

1.1.4 Radically Different Technology.

In this case, technology forecasting is not focused on changes to a technological system once it has been implemented but rather anticipating a new technology. There are a number of studies that examine how radically different
technologies are realized. The process of realizing a novel technology arises when there is a need that can be fulfilled using a concept that can be acted upon. This concept is nested within a number of constraints that further refine what the technology should be, subsequently leading to an idea that can be translated into a physical reality (Arthur, 2005). While this process seems rather simple, there are multiple inherent complexities, such as societal needs, economic concerns, risk aversion, and integration into existing system.

The above process has been examined using simple computer models that over time demonstrate the creation of increasingly complex novel elements (Arthur & Polak, 2004). In the computer simulations, Arthur and Polak (2004) found that the expanding of elements proceeds in clustering fashion, as key elements quickly lead to the creation of other new elements, while others become obsolete. Finally, the simulation found a trade-off between the number of prescribed goals and the creation of new elements. When narrowly focused goals were introduced the elements became increasingly complex to meet the needs of the prescribed goals to the detriment of the development of more general functionality. On the other hand, if very high-level goals were the only constraints introduced into the model, the new complex elements for the system never came to fruition (Arthur & Polak, 2004). This simplified model illustrates some of the complexities inherent in the process of new technology generation; however, this model has not been applied to the creation of an actual technology that is integrated into a complex system. The constraints and adequate environment definition would at least be a cumbersome process, if not
impossible to define. Similarly, the number of tractable technologies that are 
generated from a random combination of previous ones is minimal; however, in the 
model this is how a new element is formed.

More recently, complex examples have been constructed using an actual 
technological innovation as a test case for another type of model. When 
retrospectively examining technologies for potential signals of subsequent new 
technology, there is a quantitative driven model that captures information such as 
price and key factors of interest. The “fuzzy” Pareto frontier is an optimization-based 
approach that attempts to quantify new technology where uncertainty exists (Smaling 
& de Weck, 2007). By quantifying specific attributes that are important to the 
technology being examined, an exponential decay function (optimal curve) is plotted 
with technology variations points where those found to be on the function are more 
optimal that those farther away. The graph represents an opportunity versus risk plot 
on variations of a new technology. This has been applied to aircraft and automotive 
technologies; however, new technologies in health care have yet to be examined. 
This model is limited in the parameters that are chosen to be representative of a 
technology. Additionally, it does not take into account implementation complexities 
that may arise during manufacturing nor does it account for competing market 
technologies.

The current research used a telemedicine example to further explore the 
evolutionary technology change section that is grounded in cognitive systems
engineering principles. The basic principles of the discipline that are considered vital to the exploration of this nature are discussed in turn.

1.2 Cognitive Systems Engineering

Naturalistic studies of operators in complex fields of practice have focused on points of technology change, and have revealed types of discontinuities between the anticipated and the actual effects on human performance following the introduction of new devices and systems (Woods and Dekker, 2000; Woods and Hollnagel, 2006). These studies remind us that people adapt technology through use and transform the nature of practice—people in multiple roles and at multiple levels of an organization adapt their strategies, modify their roles and interactions, change performance expectations, and tailor the devices to meet their needs in demanding operational environments (Cook and Woods, 1996; Woods and Roesler, 2007). One classic example is the mode confusion problems that arose following the introduction of new levels of cockpit automation and the practitioner, organizational, and industry-wide adaptations that followed to mitigate these problems (e.g., Lenorovitz 1992, Sarter et al., 1997, Woods and Sarter, 2000).

Another classic is Grudin’s law (Norman, 1988): new software systems are unlikely to be accepted or used as designed when those who pay the cost in workload do not receive benefits from the new technology—only people in other distant roles receive the benefit. The operation of Grudin’s law is seen in repeated failures of many attempts to introduce computer information systems in health care clinical
contexts. In the past, many specific system designs only provided benefits to distant parties, while the new systems added new work or constraints on health care practitioners who already risked workload saturation (Patterson et al., 2002; Ash et al., 2004; Koppel et al., 2005; Wears & Berg, 2005). Grudin’s law suggests that, to project trajectories of adaptation, one should examine closely who pays the costs in terms of new workload or the risks of new bottlenecks, and who receives the workload benefits from the new information or activities (Cook and Woods, 1996). The changing distribution of workload costs and benefits over different roles and levels of the organization is an important determinant of how people adapt to use new systems.

The nature of coordinated activity is complex at best, hence exploring ways that facilitate this process could potentially minimize negative effects of misinformation, missed assessment, and events requiring specialized expertise. Specifically, recent literature focuses the use of collaborative cross-checking in order to overcome difficulties associated with both detection and subsequent recovery, which would be highly relevant to telemedicine. Collaborative cross-checking is defined as a multi-agent event, where each agent has a distinct perspective that involves verifying information (Patterson, Woods, Cook, & Render, 2005). Collaboration in cross-checking is necessary when examining work because the nature of work involves multiple parties that must synchronize and coordinate in the face of changing situations (Woods & Hollnagel, 2006). This type of collaboration involves shifting from one party to another and the information transmission that
occurs between these parties during events such as shift changes. The most prevalent examples of these collaborative cross-checks seem to involve health care, but also have been examined in nuclear power, railroad dispatch, space shuttle mission control and ambulance dispatching (Patterson et al, 2004).

Additionally, multi-agent coordination for action is where multiple agents interact; this does not require some anomalous event to have taken place. A specific example of this would be accessing a specialist when further specialized knowledge is critical to patient care (Leape et al., 1999). The specialist who is an expert in the area would have more complete patient management knowledge and would be better able to handle changes in strategy and goals than the less expert individual (Charness, 1994).

Modifying plans in progress suggests that during or after an event a collaborative cross-check would be used to evaluate the current course of action and revise the plan based on that assessment (Watts, Woods, & Patterson, 1996).

Sensemaking has been explored in other environments including military operations. In military operations, the idea of problem detection was explored in terms of reframing the situation. Thus the other strategy of attending to new information would be included under this strategy (Klein, Pliske, Crandall, & Woods, 2005). Klein et al. (2005) suggest that each cue in isolation does not indicate that there is a problem, but when taken is sum with other cues an anomaly might, in fact, have occurred. This is why timely updating and revision is included in the larger picture of sensemaking. Further they suggest that important factors like the number and variety of cues, the expected trajectory and attending to bifurcation points (i.e.
when an unstable temporary state and proceed to one of several stable states, so intervention could potentially upset this balance). And in the military examples from Klein et al. (2005) the absence of an event may also be cause for concern. Similarly, in studies of intelligence analysis, studies have found that intelligence analysts synthesis multiple sources of information that corroborate potential hypotheses, which lead to the construction of a story about what happened (Patterson, 1999). This study highlighted the potential vulnerabilities of this type of process, especially when outside base of expertise, time limited and a large data set. One of the vulnerabilities discussed was the sources of inaccurate information which came from using default assumptions that did not apply, incorporating information that was inaccurate, and relying on outdated information.

The general observation is that technology change transforms the nature of practice. Previous research results have built up a pattern base of how people work around complexities created by new technology or take advantage of new capabilities provided by such systems. These patterns of transformation provide a sufficient basis to develop projections of how new technologies will be adapted and produce change in ongoing fields of practice. In this paper we will demonstrate how these archetypes can be used to explicitly project a set of trajectories that capture how people in various roles may adapt, work around, and exploit new technology in ways that change the nature of work. The projections of trajectories of adaptation include diagnostic cues that observers of the change episode should look for to provide feedback to developers about the adaptive trajectories actually triggered by the new
device or system, about the complexities users are adapting around, and about the innovative tailoring underway that exploits new capabilities. Early recognition of the signs of adaptive change can help steer technology change onto more productive trajectories quickly.

For example, complexities in design create micro-cognitive bottlenecks, which lead users to develop gap-filling adaptations to try to make the devices fit the context of use. Some new technological capabilities can support users to better carry out basic macro-cognitive functions (Klein et al., 2003). This quickly leads to expansive adaptations that are innovations by leaders and exploit the new affordances, thus enabling faster, better, longer operational tempos. The new affordances can be exploited to extend the scope and reach of key human roles over wider areas and to more distant settings. Next, the telemedicine example that is the test case for the research presented is described in detail.

1.3 Description of the Electronic ICU (e-ICU)

Since the publication of *To Err is Human: Building a Safer Health System*, the issue of patient safety has increasingly come to the forefront of health care organizations (IOM, 1999). In order to facilitate patient safety in health care many organizations have turned to emerging medical information technologies. In fact, *Crossing the Quality Chasm* (IOM, 2001) report discusses the need for fundamental changes in the delivery of health care, including the technologies utilized. The cost of healthcare is increasing; expenses nationally totaled 2.1 trillion dollars in 2006, which
is an increase of 6.7% over the previous year (Catlin, Cowan, Hartman, Heffler, & National Health Expenditures Team, 2008). This increase coupled with an aging population increasingly stresses hospitals, making it even more vital to discover promising future technological applications that will aid in the efficacy and stabilization of the health care field. Within the hospital, the intensive care unit that cares for the most severely injured and sickest patients is an area where infusing new technologies to decrease the patient’s length of stay and mortality is of particular interest. One such information technology that has seen increased use in recent years, and the focus of this research, is the electronic intensive care unit (e-ICU).

The e-ICU has been described as a novel way to handle a number of problems including shortened response time and providing specialist care (Orlovsky, 2005). The e-ICU has been implemented in more than 200 hospitals and more than 40 hospital systems nationwide since 2000. Currently, an estimated 4 percent or approximately 3,850 of the ICU beds in the United States are under e-ICU observation. A previous study cited cost and organizational cooperation issues as the main barriers to more widespread use (Tele-ICUs, 2007).

The e-ICU is a remotely located facility designed to supplement ICU care at the bedside by providing remote, instantaneous, 24-hour access to experienced physicians (intensivists) and nurses with specialized ICU expertise (Beckley, 2003; Breslow et al, 2004; Celi et al, 2001). The e-ICU was modeled on an air traffic control center for the most critical patients in the hospital, those in the intensive care unit (VISICU, 2007). The e-ICU has been considered a novel piece of technology that
helps to function as an external representation providing memory aids and conveying easily accessible patient information; however, this does not take into account the whole system in which the e-ICU is being integrated. The e-ICU provides two main components: access to specialized expertise and technology tools to help both on-site and remote practitioners do his/her job better, more safely and quicker (Breslow, 2005). Individuals in the e-ICU monitor patients via a control center, which has access to patient physiological data, treatment plan, and medical records. E-ICU personnel use a combination of approximately six computer screens configured to each user’s specific needs in order to monitor the patients (Figure 3). Specifically the physicians and nurses in the e-ICU have access to real-time vitals (e.g. blood pressure, heart rate, etc), vital tracking over time, remote 2-way audio and 1-way video feeds, and the electronic patient record, which includes history, labs, and notes. In addition to the patient data the system has “smart alerts” that are alarms connected to patients based on a change in the patient’s vitals over time. Finally, the e-ICU software allows users and managers to create reports about outcomes, practice patterns, resource utilization and clinical operations (Breslow, 2005).
A single published study has been conducted comparing data prior to the implementation and with the e-ICU, the e-ICU was credited with a 25% reduction in mortality rates and 17% reduction in average lengths of stay (Becker, 2002). Other findings indicate that mortality and hospital length of stay are reduced with the introduction of the e-ICU, although less dramatic than Becker (Tele-ICUs, 2007).

In the e-ICUs, the e-ICU physicians have the authority to write orders for patients in the ICU like the attending physician does. This creates a unique situation that enables around the clock remote intensivist physician care, in spite of the national shortage of intensivist physicians (Breslow et al, 2004; Celi et al, 2001). Intensivist care for patients in the ICU seems especially important considering studies where a patient’s risk of mortality while in the ICU was reduced as well as the amount of time a patient spent in the ICU when an intensivist was available 24 hours a day (Ghorra, et al., 1999; Pronovost, et al., 1999). Additionally, Rosenfield et al. (2000) found that
the number of complications a patient experienced decreased as well. These types of findings have led patient safety advocacy organizations like the Leapfrog Group to introduce intensivist staffing standards in ICUs. The Leapfrog Group’s standards are:

1) Hospitals’ ICUs should be managed or co-managed by physicians certified (or eligible for certification) in critical care medicine.

2) ICU physicians should be present at all times to respond to over 95% of ICU pages within 5 minutes.

3) The full-time physician should provide care exclusively in the ICU (Leapfrog Group, 2000).

Even with suggested standards for 24-hour intensivist care, a national survey of intensive care units found only 37 percent of patients in ICUs were treated by full-time intensivists (Kelley, et al, 2004). It is estimated that there would need to be over 30,000 full-time intensivists to provide the type of recommended standards, whereas fewer than 4000 intensivists are currently practicing in adult ICUs (Brilli, 2001). The e-ICU seems to potentially be a way to provide specialist care, when and where none may have been previously available.

In addition to physicians, the e-ICU nurses are either full-time in the e-ICU or provide direct care at the bedside for monitored hospitals on a rotating basis. At the observed e-ICU, the design is nurse-intensive, such that during each 12-hour shift, 5-6 nurses monitor a total of 178 patients at hospitals in a local region. Each nurse is responsible for 25 to 35 patients in no more than three different units. The nurses divide the patients according to unit, such that a single nurse may be monitoring
patients in different hospitals and in different ICU units (e.g. cardiac or neurological units). For example, a single nurse in the e-ICU would monitor the neurological ICU, where 27 patients were located. However, smaller units were combined so that each nurse was watching an approximately equal number of patients. While there is variation across different systems, this particular e-ICU is responsible for 11 ICU units across four hospitals and is set to expand into another two hospitals this year.

When monitoring the patients, a nurse usually conducts “rounds” examining the patient’s orders, labs, real time vitals, and the care plan (See Figure 4). This round is completed at least every four hours or more often depending on the patient’s condition. Additionally, the nurse monitors alarms produced by the system and contacts the appropriate person when the nurse thinks further action is needed. The ICU can contact the e-ICU nurse with either a phone call or a call button in each room that is used in the case of an emergency. Thus, if a patient is rapidly deteriorating, the nurse at the bedside can stay with the patient and provide care, and contact the e-ICU to request additional resources. This is just a general description of the e-ICU nursing tasks. Specific nuances are not discussed.
The nursing staff in the e-ICU consists of over 60 nurses, a third of which are dedicated full time to the e-ICU. The other two-thirds still work in a traditional ICU on a regular basis and are split between that and the e-ICU. The average experience of a nurse in the e-ICU is 15 years with a minimum of five years in order to be considered. All of the nurses currently on staff have worked in one or more of the ICUs that are contained within this e-ICU. The e-ICU has a supervisory nurse that assigns patients to e-ICU nurses, balancing similarity of monitored patients and overall workload.

A single intensivist staffs the observed e-ICU during the night shift (9 pm to 7 am) and is responsible for providing care to all of the patients that the e-ICU nurses
monitor. Like the e-ICU nurses, the intensivists are on a part-time rotation into the e-ICU and treat patients at the bedside in addition to the e-ICU patient care. Also, the intensivist has access to the same patient information as the e-ICU nurses with the addition of accessing patient x-rays and scans. During a typical evening shift the intensivist will respond to ICU and e-ICU nurses’ requests, any codes, and contribute to patient care decisions as a consultant.

1.4 Current study

Building on the previous work described above, the current study uses a diverse set of methods in order to examine evolutionary technology change. The e-ICU provides the technology test case, which was selected in part because of the dynamic, time-critical work environment, especially in the ICU. The ICU houses the most critical, high-risk patients where timeliness of information and resources can be crucial and an area that the e-ICU is said to impact patient care. A longitudinal study using a triangulation of methods grounded in the CSE literature further explores specific technology change trajectories after initial implementation. Because this study is exploratory in nature, it was hypothesized that there would be changes in the way that the technological system is used over time that are observable and measurable. These measured changes can be used to begin a set of generalizable archetypal patterns that make projections about trajectories of adaptation over the lifecycle of a new technology following implementation.
These patterns are further explored and refined with the results from the subsequent studies at the conclusion of the observational research. Using the e-ICU as a test case, a new, expanded theoretical framework of trajectories and indicators of technology change are proposed. This framework is expected to be usable not only in the medical field, which is seeing an increasing infusion of technology, but other areas as well.
CHAPTER 2

METHOD

This research was meant to be a longitudinal study that examines the e-ICU technology use changes over the period of two years. Change is only measurable when one is able to examine a multiple instances over time in order to understand what is different. To that end, the study examined data from various points in time at a single e-ICU facility.

As in previous studies, multiple methods were employed as an approach to explore issues surrounding technology change (Potter et al., 2000). A triangulation of ethnographic methods—observations, interviews, and log analyses—were used to iterate the theoretical framework. Approaching this research with multiple methods allowed the researcher to examine quantitative data and support that with more qualitative data and vis versa. The iterative nature of these experiments also facilitated a building such that observational data could be used to help understand the categories of log interventions and both of these formed the foundation for the interview questions. These methods were selected to match the desired study goals and reveal underlying processes and functions of the e-ICU. The goal of the observations was to reveal how work in the e-ICU is actually carried out, which may...
be different than a formal description of the work (e.g. the vendor description) (De Keyser, 1992; Roth and Patterson, 2004; Woods, 1995). The log analysis provided the researcher with a way to examine changes over time that were documented and actually used by the technology. Finally, the interviews provided support for the findings beyond the single observed e-ICU. The various methods will each be discussed in detail in the following section.

2.1 Pilot interviews and observations

In order to gain foundational knowledge surrounding the e-ICU, prior research included ethnographic observations in traditional Intensive Care Units (ICUs). The observation sessions were 8 to 10 hours over a period of 2 days in order to learn more about the operations of the ICU. Handwritten notes were collected and subsequently transcribed. If questions arose a nurse was consulted. Additionally, four interviews were sequentially and opportunistically conducted with people with knowledge of e-ICUs, including a manufacturer representative. Handwritten notes were collected and typed for each interview, and they were conducted over a period of four months and were between 15 minutes and 2 hours long. All of this material was used to gain a preliminary understanding of the electronic ICU and its relationship to the ICU for subsequent study and analysis.
2.2 Cognitive Task Analysis

2.2.1 Participants

Participants were eight e-ICU nurses and one intensivist in a single e-ICU that is located in a medium-sized, midwestern city. All participants gave consent as per IRB-approved methods. At the studied e-ICU, the structure is nurse-intensive, such that during each 12 hour shift, 5-6 nurses monitor a total of 178 patients at 6 Intensive Care Units (ICUs) in a local region. Each nurse is responsible for 25 to 35 patients and has an average of 15 years of experience. All of the nurses had worked a minimum of five years before coming to the electronic ICU and each still did shift work in one of the ICUs that are monitored by the electronic ICU. No other demographic information was collected and participants received no compensation for participating in this research.

2.2.2 Procedure

The data was collected via direct observations by a single experienced observer in a single e-ICU. Overall, the observations lasted approximately 40 hours over a period of five days and included a night shift. Observation sessions were between 30 minutes and 3 hours at a time. The observations were started after the participant had given consent at which point the observer would sit down next to the participant and initiate observations.

During observations, each participant managed his/her patients and navigated through the e-ICU computer system. The observer would ask the participant to
explain what they were doing, what they were looking for, and how they were responding to different inputs in the system. During periods of low workload, questions were asked opportunistically to clarify observed behaviors and elicit potential explanations for reductions in mortality and lengths of stay using the e-ICU. The observer took handwritten notes of these conversations and removed any identifying participant information as well as any identifying patient information. The observer subsequently transcribed the handwritten notes.

Initial, preliminary insights were discussed immediately following observations with the research team and observed personnel. Functions of the e-ICU were iteratively grouped and categorized (See Table 2.1). Debates about categorization highlighted a primary distinction between functions of the observed e-ICU as currently designed, functions of alternative (not directly observed) configurations for the e-ICU, and projections about future trajectories for the technology over time. Categories of functions and projections were then made based upon a combination of top-down synthesis of partial proto-frameworks of macrocognitive functions and “cognitive laws” (Woods and Hollnagel, 2006) and bottom-up data analysis. The top-down synthesis allowed the researcher to examine the bottom-up data in a more abstract fashion which could potentially be translated into other domains. Additionally, in this case it illuminated the difficulties and techniques utilized of the nature of practice from a cognitive systems engineering perspective.
2.3 Log Data Analysis

2.3.1 Procedure

The data was comprised of a subset of an exhaustive intervention log that the e-ICU nurses keep for their own purposes. The log was something that was initially unique to the studied e-ICU, but is spreading to other e-ICUs and is an excel spreadsheet that records e-ICU interventions as recorded by the e-ICU nurse. It includes the patient, intervention description, intervention classification, as made by the e-ICU nurse into categories from Table 2.1, and in select cases, time and outcome of intervention. The intervention logs record every interaction between the e-ICU nurses and their ICUs. These interactions may be initiated either by the e-ICU or ICU and usually facilitates an ICU action to be taken. The data consisted of two consecutive months in 2005, eight and nine months respectively after the implementation of the e-ICU and an additional month two years later in 2007. In sum, there were 2301 intervention log records, in which the first month in 2005 contained 382 entries, the second month in 2005 contained 744 entries, and the month in 2007 contained 1175 entries.

During analysis, the function of each recorded intervention was initially categorized by the e-ICU using the codes developed by the direct observations from above. Independently, nurses categorized each log entry for their own purposes (see Table 2.1). The human factors categories were created by augmenting and iterating the nurses’ categories as well as the observation categories. Although the nursing codes gave useful insight, they were frequently different. For example, the entry
“bedside nurse concerned about chest tube placement, wants a chest x-ray to confirm placement. Dr ordered chest x-ray.” was categorized by the e-ICU nurses as “other,” but was categorized for this analysis as “physician action.” In this case, the ICU nurse was concerned for the patient and contacted the e-ICU nurse who put the bedside nurse in contact with the e-ICU physician. The physician was able to respond to the ICU nurse’s concern by writing an order for an x-ray to check the line placement. Here the e-ICU physician utilized all of the information available to him via the e-ICU to make an informed decision about the patient’s care and ordered the care necessary. The re-categorization was done to group interventions more into functional groupings rather than physical characteristics or adherence to specific best practice recommendations (e.g. ventilator bundle and creatinine clearance).

After categorization codes for the function of the technology were finalized and all the data were re-coded, the data were analyzed for changes over time. The analysis of the intervention log data was examined using a Chi-square goodness of fit comparing the log categories at the various times with a theoretical expected distribution of no difference across the collection times.
<table>
<thead>
<tr>
<th>E-ICU Nurse Categories</th>
<th>Observation Categories</th>
<th>Human Factors Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labs</td>
<td>Lab result</td>
<td>Lab result</td>
</tr>
<tr>
<td>Creatinine clearance</td>
<td>Missing information</td>
<td>Missing information</td>
</tr>
<tr>
<td>Vital sign change</td>
<td>Vital sign change</td>
<td>Vital sign change</td>
</tr>
<tr>
<td>Patient safety</td>
<td>Reconcile with record</td>
<td>Reconcile with record</td>
</tr>
<tr>
<td>Alarms off</td>
<td>Bedside request</td>
<td>Bedside request</td>
</tr>
<tr>
<td>Page MD</td>
<td>Patient safety</td>
<td>Patient safety</td>
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<td>Ventilator bundle</td>
<td>Best practice</td>
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<tr>
<td>Other</td>
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<tr>
<td></td>
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<td>Physician Action</td>
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<tr>
<td></td>
<td></td>
<td>Other</td>
</tr>
</tbody>
</table>

*Table 2.1: Codes for E-ICU Functions for Logged Interventions*

2.4 E-ICU Interviews

2.4.1 Participants

The participants were managers and directors for various e-ICU across the country who voluntarily participated. No demographic data was collected from the participants themselves; however, in the interest of the research, the interview was focused on the e-ICU, so demographic information about this was collected instead.
2.4.2 Materials

The interview consisted of a number of basic demographic questions about the e-ICU that the participant supervises including the number of beds monitored by the e-ICU and the staffing. Additionally, there were four interview questions that were decided upon in discussion with an expert in the medical field. The questions were:

1) How is the e-ICU working with your hospital system?
2) What are the most and least useful things you feel that the e-ICU provides?
3) What has been surprising to you about the implementation of the e-ICU?
4) What do you see as the unrealized potential of the e-ICU or what opportunities do you see it being used for in the future?

2.4.3 Procedure

The participants received an email asking for their voluntary participation to be interviewed about their e-ICU for the research study. The interviews were thirty to forty minutes in length and the researcher phoned the participant at a previously agreed upon time. The researcher started the interview by providing a 2-3 minute overview of the previous research conducted on the e-ICU and why she wanted to talk with the participant.

Next, the participant was asked to talk about his/her e-ICU in terms of the structure, size, staffing, location, and training. If the participant did not talk about any aspect of the e-ICU then the researcher would specifically ask about it. After preliminary descriptions about the e-ICU were gathered, the researcher proceeded to ask the participant the four main interview questions in a sequential fashion. At the
conclusion of the interview, the participant was thanked for his or her time and participation and given any contact information requested.
CHAPTER 3

CURRENT E-ICU SYSTEM ANALYSIS

This chapter presents the results of the research study and synthesis of this material examining the historical change of the e-ICU use over time. In order to understand what is changing about the e-ICU technology, use over time, an understanding of the current functions of the e-ICU is needed. The cognitive task analysis completed using the qualitative data from the ethnographic observations reveals the functions of the e-ICU that was collected at the mid-point of the longitudinal study. Next, the invention log analysis utilized the functions revealed in the cognitive task analysis to examine those functions longitudinally. Finally, the interviews of the e-ICU managers examined the applicability of the found functions to other e-ICUs. Each will be discussed in turn.

3.1 Cognitive Task Analysis

The ethnographic studies revealed the flexible nature and multiple processes used by those in the e-ICU. Previous studies have revealed that the nature of the health care system increases the complexity in the delivery of care (Bowen, 2005).
This study examines how the e-ICU technology functions to exploit and constrain the ICU system. During the analysis phase, three primary groupings emerged about how the observed e-ICU currently functions: anomaly response, access to specialized expertise, and sensemaking. Each of these will be discussed in turn.

3.1.1 Anomaly Response

A commonly described benefit of the e-ICU, in particular by nurses, was “an extra pair of eyes.” Similarly, a frequently cited explanation for the reduction of length of stay and mortality, in particular by the manufacturer and other proponents of the technology, was quicker action in response to anomalies. In particular, it was explained that many alerts (e.g., abnormal lab results) are not noticed and therefore acted upon by ICU nurses until they are at a computer console. Therefore, the e-ICU nurses have the ability to receive anomalous indicators in a more timely fashion.

Based upon these statements, a somewhat surprising finding was that e-ICU nurses were never observed to immediately contact ICU nurses, e-ICU physicians, or ICU physicians when alerts were received. Instead, the e-ICU nurses actively employed strategies to reduce the false alarm rate, and, therefore, also interruptions. The first response of the e-ICU nurses was almost always to immediately review other information to determine whether the alert was a false alarm. For example, an e-ICU nurse received an indication of a sharp increase in blood pressure. She looked at the trend plot for blood pressure and then manipulated the video camera to look for signs of labored breathing, skin color, and skin moisture. When she determined that immediate action was not necessary, she then examined other current vital sign data,
previous trends, and any medications or orders that could potentially explain the increase. Since the e-ICU nurse did not believe that the blood pressure change was a true anomaly that justified interrupting the ICU nurse, she said “I’ll keep an eye on that” and then started cycling through her other monitored patients. She described that if there had been a problem, she would have contacted the ICU nurse via telephone and presented a summary of the situation. In many cases, no communication occurred between e-ICU and ICU personnel following alerts.

Additionally the researcher observed the e-ICU personnel supporting anomaly response at the request of bedside ICU nurses. For example, if a patient develops pressing cardiac issues, the ICU nurse pushed a button on the wall to contact the e-ICU. The e-ICU can help to recruit resources, such as physicians, specialists, and equipment that may be elsewhere on the floor or even in the hospital. In the observed case the e-ICU nurse was able to alert the e-ICU physician so that the intensivist could assist the bedside physician. A feature under consideration, but not currently implemented, is a robotic device that can be operated by e-ICU personnel remotely in the event that a rapid response is needed.

In addition to more timely problem recognition, the e-ICU software provides overview displays and trending plots not available to ICU nurses. As such, trend graphs and other visualizations of continuously sensed data can facilitate pattern recognition. Although not directly observed or reported, this capability might enable e-ICU nurses to recognize anomalies that progress more slowly or are not currently alerted.
3.1.2 Access to Specialized Expertise

The e-ICU can be viewed as a technology that enables new types of coordinative interactions. The most salient suggestion proposed by the manufacturer representative is the ability for hospital personnel to access real-time specialized critical care expertise at any hour of the day or night by pooling the resource across hospitals. In particular, the e-ICU technology provides access to specialized physician expertise, which correlates with reduced risk-adjusted mortality (Provonost et al., 1999), in a situation where there is a growing intensivist shortage (Greene, 2002; Kelley, et al., 2004). One study estimated that 53,850 lives would be saved annually in the United States if a patient advocacy group’s (Leapfrog Group composed of more than 1000 large health care purchasers) recommendations were adopted by all non-rural hospitals with ICUs (Birkmeyer et al., 2000). The Leapfrog Group estimated in 2000 that 10 percent of ICUs in the United States conformed to all three of their recommended standards:

1. Hospital ICUs should be managed or co-managed by physicians certified (or eligible for certification) in critical care medicine.

2. ICU physicians should be present at all times to respond to over 95 percent of ICU pages within five minutes.

3. A full-time physician should provide care exclusively in the ICU.

Our observations and interviews suggest that the e-ICU physicians are arguably better equipped to serve as on-call physicians from the hospital, despite the increased coordination cost of having another person write orders. First, in many
hospitals, on-call physicians make decisions about patient care without access to patient records or visual access to the patient. Although not reported during interviews, an additional advantage is that the e-ICU physician may not be fatigued or sleeping when called. E-ICU nurses perceived that ICU nurses felt more comfortable accessing e-ICU physicians at a work location than at home, particularly on the weekends. Finally, in one interview, an ICU physician reported an increased quality of worklife benefit in that “Doctors can sleep at night.” Presumably, this also benefits patients in that ICU physicians are less fatigued when providing care.

Our observations uncovered an unexpected function: e-ICU nurses mentoring junior ICU nurses. Traditionally, nurses would have several years of experience in less critical areas prior to working in the ICU. Under the current and growing nursing shortage (Rosseter, 2007), it has become increasingly accepted for recent graduates (so-called “baby nurses”) to be immediately placed in the ICU with standard staffing ratios. Given that Aiken and colleagues’ (2003) research suggests that nursing education and experience is associated with mortality and failure-to-rescue rates, it is possible that the reduction in ICU mortality could partly be explained by this function. The highly experienced e-ICU nurse can impart critical knowledge about medications, procedures and policies that the inexperienced nurse may not know. For example, an ICU nurse was observed to call the e-ICU to inquire about the best procedure for re-warming a patient suffering from hypothermia. The e-ICU consulted with other e-ICU nurses and the appropriate medical textbook about the number of degrees per hour that a patient could be safely re-warmed before responding to the
ICU nurse. E-ICU nurses described that they can respond to such requests immediately based upon their knowledge, real-time turn and ask other experienced nurses in the e-ICU, or take the time to look it up in other sources, such as medical textbooks. At the observed e-ICU, nurses had at least five years of nursing experience. In addition, it is possible that the increased accessibility of e-ICU physicians and other experienced e-ICU nurses augments their knowledge base.

As noted in the participant interviews, a potential benefit of remote access to specialized expertise is support for informed decisions about whether to transport patients to different locations to receive specialized care. For example, there is an e-ICU facility in Hawaii that monitors a military hospital located in Guam. The manufacturer representative described that e-ICU personnel help those in the facility determine if patient evacuation is necessary and gauge the stability of the patient to transport to an American facility. This was also applicable to rural locations where specialized care is located at another distant hospital, such as in Alaska.

3.1.3 Sensemaking

Although the first two functions could arguably be accomplished through on-site personnel, a “side effect” of having remote personnel that are physically isolated from the monitored hospitals is that they are protected from interruptions and are not able to easily go to the e-ICU to provide direct care for overwhelmed personnel. However, over time the e-ICU personnel may be utilized as a resource in response to other pressures other than bedside care. The e-ICU technology supports sensemaking in that e-ICU personnel have timely, convenient access to data and the resources to
synthesize them. Due to the nature of the environment, the e-ICU personnel are able to examine in detail linkages that might otherwise be overlooked. Overall, they have the freedom to synthesize and make sense of the “big picture,” such as whether a patient is “dry or wet.” The bedside nurse will be physically caring for the patient, administering various drugs, and may not be looking at the long-term patient vital sign changes. Meanwhile, the e-ICU nurse is able to examine the patient’s vital sign changes over time and EKG changes in order to gain an understanding of whether the patient is “wet or dry.” Several nurses reported that the e-ICU is different from being a bedside nurse because “you can focus on critical thinking, without being interrupted to do physical tasks.”

3.1.4 Summary

The general functions found during the observation create a preliminary descriptive account of what occurs during e-ICU operations. Within these general functions are more specific functions that were used to categorize the intervention log data; however, more categories were needed than what was observed to accurately classify the data.

3.2 Intervention Log Data Analysis Results

A total of 2301 intervention log records were included in the analysis, where the first month in 2005 contained 382 entries, second month in 2005 contained 744 entries, and 2007 contained 1175 entries. The log record entries were sorted into a
total of 11 categories by a single researcher during analysis. In order to examine the reliability of the researcher’s entry categorization a measure of agreement was conducted using Kappa. A random sample of 90 of the entries was categorized by another researcher resulting in a Kappa score of .80, which indicates a substantial or good level of agreement (Landis & Koch, 1977). No further analysis was conducted on how the log entries were categorized as a result of the Kappa score. Subsequent analysis focused on the change in the number of data points in the categories across time. The results from the Chi-square goodness of fit analysis revealed that 7 of the 11 (64%) log categories were significantly different at the 0.05 level after two years, but no changes were detected between the first and second months of 2005 (see Figure 3.1).

As can be seen in Figure 3.1, 39.79% and 38.17% of the interventions in the first and second months, respectively, in 2005 were lab results, whereas only 18.21% of the interventions were lab results in 2007; this difference is significant, $\chi^2 = 85.84$, $p < 0.05$. The missing information category contained data points where information was missing from the Phillips monitor or the bedside alarms were turned off in 2005 there where 17.28% and 15.73%, respectively, whereas 27.83% of the 2007 interventions were; this was a significant difference, $\chi^2 = 35.05$, $p < 0.05$. Other categories that revealed significant differences were: vital sign change, $\chi^2 = 11.78$, $p < 0.05$; physician action, $\chi^2 = 23.06$, $p < 0.05$; bedside request, $\chi^2 = 37.97$, $p < 0.05$; best practice, $\chi^2 = 9.26$, $p < 0.05$; and education $\chi^2 = 20.24$, $p < 0.05$. On the other hand, the categories that revealed no differences were reconcile with record $\chi^2 = 3.28$. 

53
\( p > 0.05 \); patient safety, \( \chi^2 = 3.08, p > 0.05 \); patient request \( \chi^2 = 1.26, p > 0.05 \); and other, where there was not an adequate amount of information to accurately categorize the intervention, \( \chi^2 = 2.67, p > 0.05 \).

**Figure 3.1:** Log data percentages for categories at three different times.

(* = Significant difference)
The intervention log analysis data categories can be adapted to further explore and support the functions of the observations. The observed function of anomaly response relates to the smart alarms and alerts found in the lab results and vital sign change. The category of lab results is an intervention in response to an anomalous lab result (e.g. “smart alerts” in the software), and vital sign change is an intervention in response to a continuous change in a patient’s vital(s) (e.g. “smart alarms” in the software). The observational category of anomaly response also corresponds to the log analysis category of reconcile with record where the e-ICU nurse would intervene when there is a difference between the patient record and bedside care (e.g. the patient order says that the patient is suppose to be receiving food by mouth, but that patient is on the ventilator and cannot receive food by mouth). The final intervention log category that corresponds to anomaly response is patient safety, which was an e-ICU nurse intervention where there is a call to protect the patient in an unsafe situation (e.g. the patient is trying to get out of bed without the help of anyone).

The function of access to expertise from the observations relates to the intervention log analysis categories of bedside request, which were interventions at the request of the bedside personnel, and patient request, which were interventions at the request of the patient. Additional categories from the intervention log analysis that correspond to access to expertise are education, where the e-ICU helps the ICU in mentored learning, and physician action, where the physician acts in some way to help the ICU (e.g. the e-ICU intensivist may order a different medication for a patient).
The e-ICU observation of the sensemaking function is the intervention log analysis category of intervening in the case of a best practice, which is an intervention that involves the bigger picture and supports standards like the 100000 lives campaign. The final category that was found in addition to the three primary groupings is the missing information category, which is an intervention when information is missing from the bedside technology or the alarms of turned off.

All of the above results were gathered longitudinally in a single e-ICU. This is in part due to the logistics of data collection and the limited number of e-ICUs available across the country. In order to gage the applicability of these functions in relations to other e-ICUs, hence a final interview study of e-ICU managers was conducted.

3.3 E-ICU Interview Results

A total of four interviews were conducted with directors or managers of various e-ICUs and results were summarized and synthesized across the individuals for each of the four questions. Summary characteristics of each e-ICU as described by the representative are provided below:

- **Site 1**: The e-ICU monitors 202 beds in two states. There is 24-hour coverage by experienced nurses with at least 5 years of experience in critical care. There is 12-hour intensivist coverage during the evening hours (9 pm to 7 am). The monitored beds are in both urban and rural locations.
• **Site 2**: The e-ICU monitors 12 beds in 2 different locations and is a consultative model rather than a continuous staffed model. On average there are 4 patients in the ICU on a given day. This e-ICU has created mandated criteria that are in place which specify when a consultation is required; thus no smart alerts are used.

• **Site 3**: the e-ICU monitors 70 beds in 3 states. There is 24-hour coverage by nurses with at least 3 years experience in critical care medicine. There is 20-hour intensivist coverage (noon to 8 am). The monitored beds are in both urban and rural locations, where the rural ICU may consist of one bed.

• **Site 4**: The e-ICU covers 75 ICU beds and is staffed with a nurse 20 hours a day and an intensivist 12 hours a day. The monitored ICU beds reside in three urban hospitals and include both private and academic hospitals.

At each of the sites the participant thought that the e-ICU was a success and most had measurable improvements in patient outcomes. One participant stated: “I think it is providing a really valuable resource for people and has had a demonstrative impact of lives saved.” (For complete interview notes see Appendix).

The results of the interviews also reveal that there are a variety of characteristics about the e-ICU that the participants saw as most useful. The question was: “What are the most and least useful things you feel that the e-ICU provides?” As can be seen in Table 3.1 that compactly combines the participant’s responses to these questions. (Full transcripts can be found in the appendix). A synthesis of these
results point to the ability to access specialized expertise and the new capabilities that the technology provides.

These interviews reveal that similar functions are occurring in the other e-ICUs; such that the most useful aspects of the e-ICU correspond to the functions of anomaly response and access to specialized expertise. Additionally, tighter integration of healthcare professionals seem to indicate that sensemaking is occurring at other locations as well. Conversely, when asked about what they believed was least useful in the e-ICU system all interviewees tended to focus more on the social challenges and specific technology integration issues (Table 3.2). These observations did not necessarily relate to the functions of the e-ICU but none the least have an impact on how successful the functions may prove to be.

Parts of the e-ICU that are considered most useful include:

- Tighter integration among care providers (e.g. nurse and physician) as a result of the required electronic note
- Access to sufficient patient information at night rather than the on-call intensivist that may not have sufficient, timely information.
- An improved standard of care as a result of smart alarms and alerts
- Help to standardize care and improve patterns of care across locations, especially in patient transfer decisions
- Provide expansive capability in the event of an emergency
- Ability to provide around the clock expertise

Table 3.1: Participant responses to a question about the e-ICU’s most useful characteristics.
Parts of the e-ICU that are considered least useful include:

- System and data entry can be overwhelming, especially when having to learn new technology associated with the implementation of the e-ICU
- Software system compatibility issues with other medical software systems
- Cost inefficiency due to low system utilization
- Strained social relations between ICU and e-ICU
- Separating bedside care from e-ICU care

*Table 3.2:* Participant responses to a question about the e-ICU’s least useful characteristics.

Participants were also asked about unintended side effects they experienced when implementing the new system that the hospital. The specific question was “What has been surprising to you about the implementation of the e-ICU?” Table 3.3 summarizes the results of the responses that the participants gave during the interviews (for full transcripts see appendix). As can be seen in Table 3.3, a number of participants referred to the social aspects, either lack of or how quickly it occurred, as surprising. One participant stated that he was surprised with how “readily and naturally people in the ICU were able to communicate without having a face” and only a voice. Conversely, another participant believed in what he called the “naïve notion” that if the physician called from the e-ICU, a collegial interaction would
ensue; however, this turned out to not be the case. Again, while this is not a specific function it does speak to how effective the functions of the e-ICU could be.

The participant interviews found that the types of direct interactions the e-ICU personnel engaged in with patients was a surprise. For example, one participant acknowledged the unexpected uses of the e-ICU stating that she “knew that the e-ICU was going to be picking up issues and patient care problems, but never expected the e-ICU to be involved with a patient to help with the process of dying.” This corresponds to the observed e-ICU and indicates that the e-ICU functions not only as an extra pair of eyes, but an extra resource when the ICU staff is overwhelmed with patient care. Finally, one participant was surprised by the measured improvements in the outcomes of the ICU patients, which may be related to the successful operation of the e-ICU.
Implementation surprises include:

- Feeling removed from direct patient care
- Being utilized in non-traditional ways
- Lack of acceptance of the e-ICU into the hospitals
- Relationship building occurred quickly between e-ICU and hospitals
- Patient safety issues occurred more frequently than initially expected
- Underestimating the change of adding the e-ICU while simultaneously over estimating resulting usage
- More dramatic improvements in patient outcomes than initially expected

Table 3.3: Participant responses to a question about the e-ICU’s implementation surprises.

The three research studies indicate a number of results. First, even though the functions of the e-ICU were mainly studied and observed in a single e-ICU these results seem to transfer to other e-ICUs as indicated by the interviews with other e-ICU managers. Additionally, the longitudinal data suggest that the functions of the e-ICU are changing over time, some are increasing in prevalence, whereas others are decreasing. Finally, rather than focusing on patient outcomes as previous studies have done, the observations have resulted in a description of the e-ICU functions, while the intervention log data support the observed functions and their change in use over time. This section has been about change in the use of the e-ICU technology over time, whereas the next section utilizes this longitudinal historical data to project potential trajectories of the e-ICU in the future.
CHAPTER 4

POTENTIAL TRAJECTORIES OF TECHNOLOGY CHANGE

Based on the preliminary findings from the initial e-ICU longitudinal study the functions of the e-ICU were initially grouped and categorized, as seen in the previous section. Debates about categorization highlighted a primary distinction between functions of the observed e-ICU as currently designed, functions of alternative (not directly observed) configurations for the e-ICU, and projections about future trajectories for the technology over time. The functions of the observed e-ICU as currently designed were formulated based on the data analysis. Additional categories of functions and projections were then made based upon a combination of top-down synthesis of partial proto-frameworks of macrocognitive functions and “cognitive laws” (Woods and Hollnagel, 2006) and bottom-up data analysis.

Three primary groupings of patterns that would go into the preliminary framework none of which is suggestive of what is “good” or “bad” rather they are based upon common functions (See Figure 4.1). These functions are different from the initial groupings described in the current e-ICU system analysis, because the functions presented in this section relate to more abstract functions at an organizational, group coordination, and individual level. These three primary
groupings are based on the literature review, and propose preliminary indicators of change in technology use. In the studies we found the functions of the e-ICU, using those findings as well as previous literature on patterns of change, the researcher was able to propose an initial set of projected trajectories for the e-ICU. Previous studies propose trajectories that build upon current technology (Anderson & Tushman, 1990); whereas, the current research proposes trajectories based on how the organization, sharp-end users and integrated system evolves.

Unlike the S-curve model, a set of projected trajectories are made based upon the assumption that organizations adapt new technologies over time in order to take advantage of opportunities as well as in response to organizational pressures to complete work faster, better, and cheaper than previously expected. For example, an indicator of how a technology changes the system in the e-ICU is the addition of new avenues of coordination across multiple organizations and disciplines that otherwise do not exist. Additional indicators and trajectories provide branched predictions based upon whether various types of coordination are viewed as costly and therefore reduced, as opposed to increased when they are viewed as providing significant value.
<table>
<thead>
<tr>
<th>Adaptability &amp; Resilience</th>
<th>Coordination for Collaboration</th>
<th>Growth &amp;/or Decay of Effective Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transition from novel to routine funding models</td>
<td>e-ICU staff becomes dedicated rather than rotating</td>
<td>Cross-discipline interactions generate learning</td>
</tr>
<tr>
<td>Replacement model replaces supplement/complement model</td>
<td>e-ICU becomes hub for cross-hospital communication</td>
<td>Expertise degrades under economic pressures</td>
</tr>
<tr>
<td>Reduced staffing under economic pressure</td>
<td>ICU nurses reduce e-ICU interruptions</td>
<td>Roles move from novel to routine</td>
</tr>
<tr>
<td>Selectively implement system components under economic pressure</td>
<td>Expand distance between team members using remote communication technologies</td>
<td></td>
</tr>
<tr>
<td>Difficult to observe cognitive functions not preserved under economic &amp; workload pressures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology co-opted for distant blunt-end functions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adoption of technology as a safety solution to the &quot;human error&quot; problem following an accident</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migration to new settings</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 4.1: Preliminary Potential Trajectory Outcomes*
The e-ICU technology currently provides real-time access to specialized physician and nursing critical care expertise. These trajectories explore the growth or decay of expertise over time; growth can occur when multiple disciplines effectively interact and generate learning and decay can occur when investments in expertise degrade under economic pressures. An alternative model is needed and is under development to capture how complex, socio-technical systems adapt relative to pressures to succeed on economic, workload management, and adaptive capacity criteria.

4.1 Archetypal Patterns and Projected Trajectories

Three primary groupings of archetypal patterns were used to predict potential trajectories for the e-ICU: adaptability and resilience, coordination for collaboration, and growth and decay of effective expertise. Each will be discussed in turn.

4.1.1 Adaptability and Resilience

Unlike the S-curve model, a set of projected trajectories were made based upon the assumption that organizations adapt new technologies over time in order to take advantages of opportunities as well as in response to faster, better, and cheaper pressure (Woods, 2006). This technology migration based upon organizational values and incentive structures (feedback) is not necessarily “good” or “bad,” but there are predictable paths based upon common tradeoff functions.
• **Transition from novel to routine funding models**
   
The movement of a technology from an experimental or novel state to a standard could result in fewer resources being devoted to maintenance, personnel, and future innovations. An indicator could be a reduction in subsidies for e-ICU from research or innovation funds, moving towards a model of being completely funded by clinical resources.

• **Replacement model replaces supplement/complement model**
   
   As experience and trust grows with the use of e-ICU physicians to write orders, it is predicted that on-site ICU intensivists would be reduced and eventually eliminated under economic pressures and in response to recruiting issues given the national shortage of intensivists. An indication that the e-ICU is moving from a supplement to a replacement model would be a decrease in the number of ICU physicians staffing the ICU (e.g. no intensivist at the hospital at night or on weekends). This trajectory would move an organization closer to the safety boundary, making the organization less resilient and more likely to have an accident.

• **Reduced staffing under economic pressures**
   
   As the workload capability provided by e-ICU staff becomes more reliable, it is likely that some organizations will reduce bedside staffing to again push to the edge of the performance envelope. The projected trajectory would be to
reduce the ICU nursing staff because the e-ICU is completing some of the workload previously completed by the ICU personnel (Woods & Hollnagel, 2006). Rather than a nurse to patient ratio of 1:1 or 1:2, the nurses might routinely get 1:3. In addition to moving an organization closer to the safety boundary, making the organization less resilient and more likely to have an accident, this trajectory increases coupling (e.g., if an e-ICU physician or nurse is not staffed or the e-ICU technology fails, multiple hospitals are simultaneously affected).

- **Selectively implement system components under economic pressure**

Rather than implement the whole of the e-ICU technology, organizations might elect to implement, not maintain, and not replace a part of the system under economic pressure. For example, the e-ICU might be implemented without the video technology or less high quality video equipment, thus the personnel would only be able to view patient data and not the patient in real-time. Additionally, the e-ICU technology would be installed without the integration between the e-ICU and hospital system, or this integration would not be maintained with iterative versions of the software. With this trajectory, unrecognized or underappreciated functions of the e-ICU might be lost, such as the use of video cameras to reduce false alarms and interruptions of ICU nurses.
• **Difficult to observe cognitive functions not preserved under economic and workload pressures**

With this trajectory, cognitive functions that are difficult to observe become difficult to preserve in the face of economic and workload pressures. In this situation, new tasks and workload burdens, such as documentation or increased expectations for patient ratios, drive out the opportunity to perform the “sensemaking” and some anomaly response functions.

• **Technology co-opted for distant blunt-end functions**

Primary users for new technologies can change over time, often moving from “sharp end” users to incorporate more administrative, billing, accreditation, and legalistic functions. With this trajectory, indicators would be the increased use of e-ICU personnel and technology to improve billing accuracy, report abuses or sub-optimal care, or provide testimony in legal cases.

• **Adoption of technology as a safety solution to the “human error” problem following an accident**

After an incident or accident occurs, there is often an increased prioritization of safety in relation to economic and workload pressures. When the e-ICU is viewed as a solution to the “human error” problem following an accident, learning about how to improve the system, the technology, or otherwise
improve barriers to failure can be blocked. On the other hand, there can be positive “side effects” from unrecognized functions of the e-ICU that can prove beneficial.

- **Migration to new settings**

The e-ICU technology could be migrated to different types of ICUs, specifically those specializing in different populations (neonates and pediatrics), other countries, and use beyond a regional level. When technology migrates, there are often post-conditions associated with a change in setting (Woods & Hollnagel, 1987; Woods & Dekker, 2000). For example, neonatal ICUs might need adaptations to the video technology in order to remotely view patients inside “warmers.” This migration process can be managed well or poorly/not at all.

4.1.2 *Coordination for Collaboration*

The e-ICU provides new types of coordination across multiple organizations and disciplines that otherwise do not exist. A set of projections provide branched predictions based upon whether various types of coordination are viewed as costly and reduced, as opposed to increased when they are viewed as providing significant value. Previous research in health care has highlighted the importance of coordinated activity and timely flows of information and resources while remaining flexible when the plan is implemented (Ebright, Patterson, Chalko, & Render, 2003). No
trajectories are predicted where coordination structures and interactions remain stable over a long period of time.

• *ICU nurses reduce e-ICU interruptions*

Previous research has examined the interruptions in the health care setting and how it affects patient care (see Chisholm, Dornfeld, Nelson, & Cordell, 2001), the e-ICU is a new type of interruption, which may be useful and productive. As a workload management strategy, the ICU nurses are predicted to develop strategies to reduce the e-ICU interruptions; in an extreme case, there would be “gaming” of the e-ICU monitoring technology and workarounds to reduce, delay, or otherwise enable selective responses to e-ICU requests. Alternatively, the e-ICU technology might migrate over time to use new mediums for e-ICU to ICU nurse communication that queue requests, are asynchronous, or have dedicated channels.

• *e-ICU staff becomes dedicated rather than rotating*

It is recommended by an e-ICU manufacturer that e-ICU staff be shared with the monitored hospitals to facilitate communication and action in response to e-ICU concerns. Over time, it is predicted that e-ICU staff might become more dedicated to reduce coordination costs across organizations. In this situation, it is likely that the e-ICU and ICU personnel will have less effective dynamics of interaction and more discontinuities of care during handoffs.
• **e-ICU becomes hub for cross-hospital communication**

Over time, the e-ICU might become a hub of communication among hospitals, thereby reducing coordination costs across hospitals. For example, the e-ICU might help with recruiting ICU physician or nursing staff at the participating hospitals by expanding the available network and informal communication channels. In this trajectory, the e-ICU would become a communication center for the pooling and distribution of resources, such as developing and maintaining websites with policies and procedures. The e-ICU could also be a key leader in compiling and disseminating best practices and local innovations across the participating hospitals.

• **Expand distance between team members using remote communication technologies**

A long-term trajectory is that rather than using a regional location implementation strategy, the e-ICU could be expanded to much greater physical distances and for more hospitals (e.g. one e-ICU for all of the New England states). It is likely that post-conditions will be needed to do this effectively, such as explicitly investing in relationship development and maintenance between e-ICU and other staff with regular teleconferences and meetings.
4.1.3 Coping with complexity

One of the primary benefits of the e-ICU technology as it is currently used is real-time access to specialized physician and nursing critical care expertise. These trajectories explore the growth or decay of expertise over time. Growth of expertise can occur when multiple disciplines effectively interact and generate learning. Conversely, decay can occur when investments in expertise degrade under economic pressures.

- **Cross-discipline interactions generate learning**
  
  E-ICU physicians and nurses work in close proximity in a relatively slow-paced environment. This environment might foster new links and learning across disciplines, thereby growing new types of expertise.

- **Roles move from novel to routine**
  
  As new technologies transition from novel to routine, there is a corresponding change from staff being excited by new roles and responsibilities (the “pioneer”) to routine positions. On one hand, recruiting may be easier as the role better fits in the infrastructure, such as credentialing or having clear career trajectories. On the other hand, e-ICU personnel could potentially have reduced motivation in their roles.
• *Expertise degrades under economic pressures*

Under economic pressures, less experienced and well-trained nursing personnel, such as licensed practical nurses (LPNs) or nurse technicians, could replace the registered nurses with critical care experience. Similarly, e-ICU intensivist staffing could be replaced with physicians in training, physician assistants, or nurse practitioners. In addition, e-ICU personnel can have degraded skills over time if they do not practice sufficiently in the ICU environment. This trajectory is more likely if e-ICU personnel are attracted to the e-ICU in order to have a better work environment (e.g., light duty nurses who want/need to avoid lifting heavy patients, physicians who desire a more predictable work schedule).

4.2 Discussion of archetypal patterns

The archetypal patterns of projected trajectories of the e-ICU suggest post-conditions to manage following e-ICU implementation, both positive and negative. Technology increases the complexity of the system via unintended side effects, changes in the nature of the task, and creates new paths to failure (Woods & Dekker, 2000; Woods & Hollnagel, 2006). Over time, the complexity inherent in the system may shift and transform as resources and workload changes, thus adding a new level of complexity.

The archetypal patterns suggest a number of desirable post-conditions that could result from future technology change. Post-conditions arise from a synthesis of
technology change observations and abstracting patterns of how the organizational, collaborative, and cognitive demands and activities adapt. In anticipating potential trajectories the post-conditions serve as a landmark as to which trajectory one is operating on. For example the plurality of potential trajectories that the e-ICU could be on at one time is indicated by the patterns presented above; however this could conceivably be constrained by observations of the e-ICU and monitoring how it changes over time.

A diffusion of knowledge spread among e-ICU nurses and intensivists could result from the collaborative environment and close proximity for extended periods of time. Additionally, the influence of the e-ICU’s recommendations might expand due to increased prevalence of the mentoring function. Post-conditions, or potential effects, of the projected trajectories might include increased collaboration across organizations, such as quality improvement collaboratives (Patterson et al, 2007). This niche of becoming the hub for collaboratives is an opportunity that could potentially be utilized to improve patient outcomes in a multi-hospital system, and increase awareness about effective as well as ineffective improvements.

The healthcare environment, especially the ICU, utilizes an increasingly diverse number of resources that aid in patient care, which has corresponded to an increase in the difficulty of a single practitioner to adequately provide the range of patient care. Researchers suggest that there is fragmentation in the healthcare system as a result of the increased complexity and that to overcome this, coordination and group work is essential (Lighter, 2000). The e-ICU might increase the collaboration
among professionals at the bedside by alerting those at the bedside to potential factors that could lead to latent failures and providing a continuity of care that is functionally different than the bedside personnel.

The archetypal patterns were grounded in observations and intervention log analysis and project how the e-ICU technology will continue to transform the nature of work. It is interesting to note that the interview participants when asked to project where the technology might go in the future, no participant thought that the e-ICU was become extinct and most were pushing for expansion of the e-ICU program. As can be seen in Table 4.2 the range of answers is vast; however, every participant mentioned migrating the e-ICU technology to other areas of the hospital.

Future potential trajectories include:

- Further integration within the national hospital system
- Expansion to other areas within the hospital, such as the emergency department or in stroke care
- Improvement in standard technology hardware such as 2-way video
- Improvements in support software technology
- Greater emphasis on data visualization
- Use collected data in order to create models of illness and treatment
- Use e-ICU to access specialist resources for remote locations.

*Table 4.2:* Participant responses to a question about the e-ICU’s future potential.
Conversely, a number of trajectories undermine collaboration or increase coordination costs, possibly to the point that the resources required will undermine many of the benefits. No potential future trajectories that the interview participants mentioned including negative or neutral indications. Additionally, decreasing the expertise of the e-ICU could result in a loss of collaboration if the ICU nurse perceives the e-ICU nurse as less competent. Decreased collaboration could also result as a side effect of increasing distance and dedicated staff, where the maintenance of common ground would increase in difficulty as a result of this physical, cultural, and mindset differences (Woods & Hollnagel, 2006).

In general, many of the archetypal patterns impose negative post-conditions when changing the nature of the task, such as an increase in workload and loss of a function that was previously performed. Functions like anomaly response and sensemaking will be reduced if the e-ICU moves towards becoming the accreditation monitor for ICUs, which can lead to diffusion of responsibility over multiple goals. The issue of differential responsibility is blurred in that the responsibility and accountability to achieve different subsets of goals, in this case clinical monitoring and administrative oversight, conflict (Woods & Hollnagel, 2006). Another potential post condition is that e-ICU or ICU personnel develop covert work systems and workarounds in order to protect and manage their workload.

Another set of potentially undesirable consequences of the trajectories explored above is disregarded technological side effects. If the e-ICU is migrated to
new settings without the appropriate tailoring to the population of interest (e.g., neonatal populations might not be able to be viewed clearly due to glare on warmers), then the criterion for successful use (e.g., change in lighting above warmers) are missed. Similarly, in the wake of a celebrated accident, potential improvements to a current technology might be overlooked in favor of adopting a new technology like an e-ICU, which is seen as the safety solution. Consequently, if improvements are seen after a technology is implemented or changed, they may be attributed wholly to that technology, thus potentially missing other factors, such as the Hawthorne effect.

The undesirable post-conditions touched on above undermine and erode an organization’s safety margins, realize system brittleness, and can reveal where adaptive capacity is crucial in helping to prevent a decompensation event (Woods & Cook, 2006). A decompensation event pattern consists of an increase in effort to compensate for a growing disturbance, the response masks the presence or severity of the disturbance, followed by a sudden collapse when adaptive capacity is exhausted and the disturbance can no longer be compensated. For example, as ICU staffing gradually decreases, the e-ICU adds more anomaly response functionality to compensate for the decreasing capability of the physical ICU. This imposes new coordination requirements to bring more expertise to bear when load increases and when there are too few ICU personnel to handle the many anomalous events within a critical time period (i.e., escalation, Woods and Patterson, 2001).
4.3 Applying Archetypal Patterns to Intervention Log Data

The projecting potential trajectories described above examined the data from the observations and interviews; however the intervention log data can additionally be utilized to examine functional change in technology usage over time. Figure 4.1 examines six log functions as a percentage of time in the e-ICU spend doing the function over time. One would surmise that the more time spend on a task the more important that function would be seen in the funding models and organizational blunt-end of the e-ICU. The six functions were developed from the original 11 categories set forth in the previous section, such that an “extra pair of eyes” related to e-ICU anomaly response specifically the categories of an anomalous lab result, vital sign change, reconcile bedside information with patient record, and patient safety issues. Best practice reminders were just associated with best practice from the initial categorization, while administrative and billing was associated with missing patient information. Primed continuous consult was associated with requests from the bedside, including patient request, whereas mentored learning had to do with the initial education category. Finally, the specialist expertise function related to the physician action category.

Based on the intervention log data the graph reflects is a change over time in these functions over time. The graph shows a change in functions and what the demands of the field of practice are over time that influences the types of post-conditions of change.
In order to maintain the current functionality of the e-ICU there are some suggestions for essential post-conditions that would be required for the e-ICU to continue to have a positive impact on patient care. A number of these post-conditions come out of the functions that were found in the studies. For example, a post-condition that has the desired effect of improving patient outcomes, is the ability for the e-ICU to have the “big picture.” The observations revealed that the e-ICU nurse would construct a story of each e-ICU patient, as new information was added, the nurse further refined or changed her story. If information that was the inverse of what she expected, then the nurse would react and further explore to find out what was going on with the patient and if this is something that requires further attention and action. This also suggests that another essential post-condition would be specialist
expertise, especially since that knowledge plays a large role in one’s ability to understand the big picture of what is happening with the patient.

In order to sustain the current usefulness of the e-ICU as a protected resource, it should continue to be removed from the ICU. In the face of workload and economic pressures, future e-ICU implementation could potentially be integrated into the ICU where there is a nurse in the ICU monitoring all of the patients in that ICU (e.g. the nurse would have access to the specialized software, but physically located in the ICU). While this might have potential benefits, it also makes that nursing resource more readily exploitable. For example, if the ICU is filled to capacity, the nursing staff might be tempted to ask the e-ICU nurse to help with direct patient care, because the e-ICU nurse may be seen as an extra resource just sitting there. Conversely, the e-ICU may come to monitor many more patients than does currently, such that a single nurse or physician may be watching 100 or more patients, which would be a workload increase. Potentially, this could negate the e-ICU personnel’s ability to maintain a “big picture” of the patient’s. Thus, from the foraging literature the e-ICU personnel would become reactive rather than proactive, which may decrease the positive impact of the e-ICU (Garrett, 2007). In sum, the desired post-conditions are in part, dependent on what functions the e-ICU is desired to have. If the impact of the e-ICU is best served functioning as an “extra pair of eyes” then the necessary post-conditions are described above. However, if the e-ICU is considered having the most impact functioning as a best practice implementer, then the necessary post-conditions may be different. This is not to say that the e-ICU can only serve a
single function, but that various functions compete for resources and may pose conflicting post-conditions. The next section illustrates the beginning of a framework that explores changing trajectories over time and their respective potential post-conditions.

4.4 Proposed Framework

Previous literature has examined the effects of technology introduction from an organizational perspective (see Davis, et al. 1989; Anderson & Tushman, 1990), while ignoring technology change that occurs dynamically over time in the face of various pressures and constraints, as well as opportunities. The latter can account for a modification in an individual’s strategy or environment, which has been found previously (Pirolli & Card, 1999). The proposed framework utilizes the above approach to examine how potential trajectories may increase the ability to steer technologies onto more productive paths prior to a failure. The S-curve model of technology adoption is incomplete in that it only plots over time whether or not a technology is adopted.

Rasmussen, Pejtersen, & Goodstein (1994; see Cook and Rasmussen, 2005) provide an alternative concept to capture how complex, socio-technical systems adapt relative to pressures to succeed on economic, workload/quality of work life, and safety criteria. The dynamic safety model is a descriptive representation of a systems operating space. Introduction of new systems and work organizations, like the e-ICU produce sets of local adaptations that change this operating space. These shift the
organizations operating point relative to the three boundaries, shift the organization’s knowledge about where it is operating relative to the three boundaries (knowledge calibration), and shift how brittle or precarious operations may be when pushed near to a boundary.

Rasmussen’s boundary schematic format illustrates how organizational changes can constrain and restrict where the organization is operating within the space and when it is in need of making an adaptation. For example, an organization continuously moves toward a successful balance of safety, economic and workload pressures, which is within the boundaries. As an organization drifts closer and closer to the safety boundary while adapting to economic, safety, and workload pressures until a last disruption, misaction, or mis-assessment pushes operations over the boundary to produce a visibly adverse event.

Using this schematic format for inspiration, the technology change framework builds upon and transforms it at its very foundation into a set of linked expansions and constrictions. The new technology change framework consists of a performance track, rather than the organization moving within stable operational boundaries. The performance track is manipulated as a result of the creation new niches (points for expansion of capabilities) or constrictions.

The framework consists of four operational performance tracks: efficiency, expertise (quality), workload, and adaptability (see Figure 4.2). The four tracks are viewed as four perspectives that can be taken to describe the work system. The efficiency track is akin to Rasmussen’s economic boundary in that the perspective is
focused on maximizing the organizational productivity while minimizing operational costs. The expertise performance track focuses on quality of care in healthcare or in a larger context it would be associated with quality of the process or product. The workload performance track is related to the work and tasks that individuals are required to accomplish, hence the boundary is at the point where manageable workload becomes unacceptable workload. Finally, the adaptability performance track is the operational safety adjusted to relative risk at that point in time for the organization.

As can be seen in Figure 4.2, the performance track creates an area in which the role operates, that is smooth and regular in shape as the work is routinized or adapted to routine. However, the performance track can be disturbed in either an expansion or constriction. An expansion would cause the specific performance track to bulge out as a new niche is created, which would increase the area of the entire space. The bulge represents the potential to better meet goals associated with that track; leaders recognize this potential (a niche) and attempt to move operations in order to capitalize on that potential. This expansion could be for a multiplicity of reasons, including extra resources that or not being utilized, less time consuming workarounds, and process improvements.

For example, within the ICU if a new 24-hour physician coverage mandate was added, this would create a new niche within the expertise performance track. Previously, when only an on-call physician was available in the middle of the night, now a specialist resource would be available. Conversely, if this mandate were to
occur, there might simultaneously be a constriction in the efficiency performance track, because now extra resources have to go into funding an intensivist, who may or may not be utilized to his full capacity during the nighttime hours. This constriction is can be an obstacle or bottleneck that impinges upon the roles routinized performance path. This shows that an expansion on one facet of a single perspective can reverberate throughout the performance track to other facets of other perspectives, creating constrictions (e.g. offset pattern).

Another pattern of change would be a constriction in one facet of a single perspective that also constricts other perspectives of the performance path, which stimulate the creation of workarounds. Conversely, another pattern of technology change would be an expansion in one facet of a single perspective that also creates expansions in other facets of other perspectives. Over time expansion and constrictions become normalized and expected parts of a person or group performing that role. This movement to a new equilibrium is captured in the representation as a movement back to a regular (circular) track (Figure 4.3 provides a notational illustration of how this is happening over time as the e-ICU/ICU combined system becomes a normal part of operations). Additionally, these linked expansions and constrictions may translate into expansions or constrictions in other roles.

Each group or organization (e.g. emergency department, ICU, and surgery unit) can be represented by an operational performance track to capture how changes create expansions or constrictions on one or more of the component tracks (efficiency, expertise, workload, adaptability). In addition, to linkages within one operational
performance track (e.g., when an expansion one facet leads to constrictions or expansions on other facets of component tracks), linkages can occur across roles. An example of this process occurred during the longitudinal observations of the e-ICU (e.g., Figure 4.4).

Figure 4.2: Linked expansion and constrictions of technology change.
The example that follows illustrates how this framework could be used to investigate potential trajectories and also indicators of specific trajectories. It starts with an examination of the ICU and consideration of why the introduction and use of a telemedicine technology would even be considered. The ICU is under consistently greater efficiency pressures due to the fact that it is the most expensive patient care facility within a hospital system. Patient care in the ICU costs 3 to 4 times more than a traditional hospital floor. This is in part due to the reduced nurse to patient ratio and that the patients traditionally require more resources as a result of severity. Additionally, the ICU is staffed with intensivists, who are highly specialized physicians that focus on critical care medicine. When hospitals look to cut costs, this is one unit that they focus on, which constricts the ICU’s efficiency boundary (as seen in Figure 4.3).

Another constriction in the ICU is the limited number of intensivists nationwide that are practicing. As noted previously, approximately 4,000 intensivists currently practice in the United States; however, in order to meet the Leapfrog Group’s suggested standards there would have to be approximately 30,000 intensivists (Brilli, 2001). The number of intensivists is not likely to increase to meet the Leapfrog standards; thus, creating a need for novel ways to comply and overcome the potential shortage and spread the limited resource of intensivist expertise.

This lack of expertise constriction also lends itself to the creation of a workload constriction. With the limited number of intensivists, the intensivists that are available create a workload bottleneck. This may be mitigated by recruiting
physicians that are not as expert to help offset the workload, which in turn may create a constriction in another hospital unit (not shown). Additionally, nurses in the ICU are usually the most experienced in the hospital, but this is not necessarily the case. Therefore, while providing highly specialized care these nurses are also not as expert in resource gathering and proactive patient monitoring strategies (Ebright, 2003).

Even in the face of all of these constrictions the ICU has managed to adapt in order to still provide patient care.

The e-ICU system was introduced and created an opportunity to address the constrictions that the ICU system was incurring. The ICU and e-ICU system created a new set of operation boundaries with new roles and pressures (Figure 4.3).

Figure 4.3: Notional example of normalization of the ICU to e-ICU system transition.
As can be seen in Figure 4.4, the new e-ICU framework may now be exploited by other parts of the hospital system, which also has its own set of constrictions. In order to overcome these constrictions the other unit, in this case hospital administration, viewed the e-ICU as a way to help monitor billing processes in the ICU. Thus, there is a transformation of roles such that what the hospital administration was once responsible for, the e-ICU now becomes responsible. The e-ICU is viewed as having the resources to more accurately monitor a set of the machines that improve the accuracy of patient billing assuming that the patient’s information is entered. The transition does not happen seamlessly and the e-ICU incurs a workload cost with the extra monitoring it now has to conduct.

The transition creates additional expansions and constrictions in the e-ICU as well as the hospital administration (See Figure 4.4). The administration experiences an expansion in adaptability by resolving the task that was helping to create constrictions within its prevue. On the other hand, the e-ICU is also seen as adaptable and expands in that area because it was able to incorporate this new task into its operations without a failure or large performance decrement. The e-ICU experiences both an expansion and contraction in the efficiency boundary, because on one hand they are improving a hospital function, but that may not be the best use of their time. The expansion in the efficiency relates to the issue of improving the accuracy of a hospital function. Conversely, a constriction in efficiency also occurs because the nurses, who are expert in the field of critical care nursing, are now not using those
skills in order to monitor the billing function and this may not be the best use of their time. However, according to comparative advantage, even though the e-ICU personnel have acquired expertise in a different area, it might be advantageous to the overall hospital system to delegate this task to the e-ICU rather than keep it in the hospital administration based on other tasks that the administration experiences (Lee, 1999).
Figure 4.4: Linkages to other units within the hospital system.
Theoretically this framework could be scaled up to examine a larger unit (e.g. hospital rather than unit) or scaled down (e.g. individual role like nursing). Projecting trajectories of adaptation, as this paper has illustrated for changes triggered by the development of the e-ICU, can support early recognition of drift toward failure boundaries. Explicit projections may support steering technology design and implementation in more productive directions, and how we might manage negative “side effects” associated with particular trajectories by instituting post-conditions following implementation of the new technology. Recognizing side effects of change can provide feedback to design activities about how to modify designs facilitate operations and feedforward to organizational management about key indicators that post-conditions are being met. The ability to project possible trajectories in order to aid in selecting among alternatives and managing post-conditions might provide an additional criterion for useful technological systems.

In the future, additional technological trajectories could be examined in order to extend and test the framework to include other forms of adaptive behavior following points of change. In addition, if a framework is created illustrating the course of a system, how can this be delineated to form an accurate account of which groups of potential trajectories are encompassed in the representation in order to accurately move toward a set of potential trajectories. Future studies should also examine how the knowledge of potential trajectories created using the framework can be translated into creating organizational priorities, in order to address organizational chronic needs rather than acute. Finally, other industries other than healthcare could
investigate the viability of this type of framework for use in their systems, which are potentially very different from the current telemedicine technology studied.

### 4.5 Conclusion

A longitudinal study using multiple supportive methods was conducted in order to identify patterns of how expert practitioners currently interact with computerized support in the e-ICU to achieve domain-specific objectives. The study made explicit projections about potential trajectories of adaptation. A number of archetypal patterns, indicators, and post-conditions were identified that could potentially occur as people in various roles adapt to the new system and work organization under changing economic, workload and safety pressures. The example of projecting trajectories of adaptation following technological change can be generalized to other episodes of technology change in other socio-technical settings in future research.
REFERENCES


APPENDIX

E-ICU Interview Notes with Managers and Directors
Participant A.

The e-ICU characteristics:

The e-ICU monitors 202 beds and has grown since its inception in 2005 when it was implemented in 70 beds. Currently, the hospital system plans to continue to add e-ICU beds through 2010 when it will encompass approximately 400 ICU beds. The hospital system is present in 7 western states with over 20 hospitals under its prevue currently. However, the e-ICU monitoring is currently present in only two of those states and one of the reasons is that credentialing and licensing has to be completed for the e-ICU staff in each state.

Staffing

Nurses:
- There are a number that are full-time in the e-ICU and include: those that have worked 35 years plus, are very experienced, and not physically able to do critical care anymore, but that are a wealth of knowledge
- Those that are full-time in e-ICU (5-plus years) but still work at bedside too by picking up shifts
- Those that have 5-plus years of experience and are shared 1:2 with the bedside
- Nurses are present in the e-ICU 24 hours a day

Physicians:
- Full-time intensivist that moonlight at the e-ICU for 12-hour evening shift. However, the participant states that it is a goal to get 24 hour coverage because some of the monitored hospitals don’t have an intensivist.

Where are the monitored beds (urban, rural)?

The e-ICU monitors both urban and rural locations. In some of the rural locations the facility have no intensivist on staff (some 24, some only daytime).

Does the e-ICU staff receive any special continuing training?

Personnel is provided with more training each time the system is upgraded. “Training has been a 2 year process” especially as the interfaces are built “smarter, quicker, and better”. The upgrade can affect the APACHE score, so they want to look at that.
How does the e-ICU interact with other computer programs in the hospital system.

They have CERNER so they have the same problems that the observed hospital has, in that the systems do not correspond with each other.

How is the e-ICU working out for your hospital system?

Currently they are looking to figure out where are they doing the most good for the cost, however the ROE has yet to actually be calculated. What they have seen is after the implementation of the e-ICU and another pediatric program is that malpractice cases against the hospital have dropped by 50%.

She quotes that she is “one of their (VISICU) biggest supporters.”

What are the most and least useful things you have found with the e-ICU?

Sometimes when the nurse has been at the patient’s bedside the day before, and is today in the e-ICU monitoring that patient that have problems not intervening. They know the nurse that is at the bedside that day is competent, but can’t help wanting to intervene.

What about the e-ICU have been surprising after implementation?

Upon implementation she knew that the e-ICU was going to be picking up issues and patient care problems, but never expected the e-ICU to be involved with a patient to help with the “process of dying”. A DNR with no family present, the e-ICU nurse knew it was happening and spoke with the patient until she could get the bedside nurse to come in and sit with him.

She was also surprised with how long it took for the bedside nurses to be okay with the change in the care process (e.g. addition of the e-ICU). Some of them took it as a personal attack against them and still do not like it.

In the newer hospitals there is actually 2-way video and she was surprised at how fast the relationship building was in these situations, specifically, the family would hit the e-lert button because they wanted to ask a question.

The number of standing patients, intubated patient trying to take out their tube, and preventing falls that the e-ICU nurses see.
Aside:
They use for best practice initiatives: and the “baby nurses” hit the button and say I can’t figure x out.” Everyone now goes through the e-ICU training course even if they work only at the bedside.

What do you see as the unrealized potential of the e-ICU or what opportunities do you see it being used for in the future?

There is this system called an eCARE mobile unit which is to help triage patient in the ED from the e-ICU, call and say what do you think about this.

She said that they deal with a large native American population that wants to keep the family member as close as possible because having to transfer them to another hospital may mean that no one is able to actually make the trip and stay with them. And the eCARE mobile unit stays with the patient as they are moved to a critical care bed. Their largest facility sees 90-100,000 patients a year, and has become a holding area. As of Dec. they were still working out the IT and nurse process. Because the ED has become a holding place for patients that potentially belong in the ICU (if no bed is available); they don’t want ED patients to fall through the cracks. In the beta location the eRN has said, “Why can’t they get a critical care nurse down there to help?” (Directors reply was that you are that critical care nurse.)

VISICU is apparently trying to expand it for use in the med surgery floor, to surgery patients and Sentara is suppose to be the first site for that (she said it hadn’t happened yet, but that the hospital was interested in this as well, but it would have to add the infrastructure.

Other facilities have thought about and are trying to use it as a Rapid Response team, with something called an eCARE mobile unit. But again the rooms have to have the infrastructure on the hospital floor and that is expensive.

This hospital system is building a children’s hospital and would like to expand to that, but she doesn’t think VISICU has the knowledge base for children (program is designed for adults).
Participant B.

The e-ICU characteristics:

The e-ICU uses a completely different practice model than a traditional one; here it is used as a consultative model and as such it is not a continuous staffed. The e-ICU monitoring technology equipment is physically located in an ICU room and monitors a total of 12 beds. On average there are 4 patients in the ICU beds, which is a low volume considering other e-ICUs.

There is mandated criteria where if met then the physician at the bedside must request a consult with the e-ICU physician. Additionally, the e-ICU has “an open door policy” in that anytime personnel at the bedside can ask for a consult. The e-ICU has been in existence for 5 years, but recently expanded another 6 beds just last year.

Patient information is entered into the e-ICU as needed and neither place has electronic record or order entry. The e-ICU has developed a template that the bedside can just print off if the bedside physicians use the EMR.

Don’t use smart alerts.

Staffing:

Nursing
- There is a nurse operator who during work hours, checks in with remote ICUs to see if they have any consults. The nurse will verbally check with the remote ICUs. If a consult is desired, a referral request is generated by the physician then the nurse operator will enter all of the patient information into the hospital. The requests can also come in the form of a fax or telephone call.
- The routine is that at about noon, which means it is 7-8 pm at the remote hospitals then the clinical coordinator (nurse operator) can look and establish time to meet and refer with the e-ICU physician, which is incorporated in the physician’s daily rounds model.

Physicians:
- There is a single physician that incorporates any e-ICU patient cases into the rounds. The consultation is a weekly assignment and it is the physician that is assigned to the intensive care unit that week.
- On an as needed basis.
- All consultants are credentialed, and talk directly with physician at the bedside. After consultation the e-ICU physician will write notes, but not
orders. Always consultant. These notes will be printed out and put into the patient’s chart.

Where are the monitored beds (urban, rural)?

Sometime people forget it is there because one is in a more rural area and the other hospital is in a more urban setting. There is one person in each location that helps and continues to help the workflow process of the consult.

Interaction with other computer programs.

The e-ICU system is not integrated with the hospitals’ information systems, thus all of the data is entered into the e-ICU system by the nurse coordinator. They do have radiology access. Coordinator types all of the information into the VISICU system after the physician at the smaller hospital asks for a consult.

How is the e-ICU working out for your hospital system?

“I think it is providing a really valuable resource for people and has had a demonstrative impact of lives saved.” However the number of patients served is relatively low, making it a very low census.

The participant believes that the e-ICU is clinically effective, but system is underutilized. Some of this underutilization is based on individual personality because it is still physician driven. They have been trying to overcome these using mandates through criteria driven, but this still makes it a little frustrating.

What are the most and least useful things you have found with the e-ICU system?

Most;

- The participant believes that the e-ICU has the ability to help standardize care in remote locations through consultative process and provide recommendations that aren’t known by those in the remote ICUs.
- It seems to be most useful during the first half of year ton of recommendations but second half less, because integrating what they are learning into care.
- Improved pattern of care across referral hospital, aircraft transport, to new facility, because physician has better picture of what has been going on with the patient.
- Additionally, the e-ICU intensivist is better able to make decisions about where the patient should be located. In some cases the e-ICU chooses not to
evacuate a patient because they can help with care everyday, or they can say to transport the patient to them now or finally, at one to the remote hospitals there is the option to send the patient to a local hospital that has an intensivist.

- There is a continuous requirement to be able to quickly and effectively be able to respond in the case of an emergency. The e-ICU helps by providing an expansive capability. When there is a surge in the remote ICU, they are able to help the patients and review information from cases that might have slipped through the cracks when the remote physician is stressed. For example, there was an explosion which badly burned and injured 6 people. Rather than the average of 2 the ICU was now in a situation where it was full and the personnel in the ICU were stressed in having to provide treatment for all patients. The e-ICU was able to step in a help provide the most current recommend specialized care for each patient according to the patient needs.

Least:
- The e-ICU as it currently functions is inefficient because of the low volume.
- Another thing that has been least useful with the system is the amount of time and energy that it has taken to get “buy in” and demonstrate value to end-user. In this e-ICU they have had providers in the ICU who don’t want anyone to be involved and the implementation of the e-ICU has actually generated conflict.

What about the e-ICU have been surprising to you after implementation?

The participant was surprised with how readily and naturally people in the ICU were able to communicate without having a face and only a voice to communicate with. When you think about other systems a lot of them try to involve a face-to-face communication because the designers worry that people would feel too disconnected. The ICU people adapted pretty quickly, it just sort of happened.

What do you see as the unrealized potential of the e-ICU or what opportunities do you see it being used for in the future?

The participant sees the e-ICU as a way to provide a standard consultation for other specialties too (not just intensivist). Whereas typically a patient is usually referred to a specialist telemedicine provides a more broadly applicable platform, where a specialist can come to the patient.

Use for other parts of hospital as well.

Actually the data that is collected has amazing potential. The physiologic data combined with the outcome data, would allow the creation of a model of illness in a way that has yet to be done. Throughout the e-ICU in the nation there is data on this
clinical work in thousands of patients a day, which could be used to create a good predictive model of illness and potentially how many days to continue on antibiotic, etc. Currently there are issues in accessing all archived data including: problems with who gets, HIPPA, and how to use it. Currently, all that data is kept and theoretically VISICU has access to use for medical research.

In the future and has been trying to use the e-ICU as demonstration program and in turn extend throughout Asia military system (especially Japan).

Finally the participant believes that the e-ICU could be used for remote monitoring of surgery.

Aside:
The participant has been doing a lot of distance learning research in addition to home health asthma monitoring, and diabetic retinapothy.

More specifically, diabetics can suffer from transverse photographing the back of the eye, however, there is just not enough time and resources to get everyone screened. The participant has done studies with standardize patients, which are actors who have portrayed disease state and with technology you can do that through distance.
Participant C.

The e-ICU characteristics:

The hospital system that has this e-ICU has hospitals and clinics in 5 states throughout the mid-west. A big factor in choosing to implement the e-ICU was the Leapfrog standards and the hospital systems saw this as an opportunity to meet the guidelines. The first hospital went online in Sept 2004, which was a larger tertiary facility. Since then they have added other critical care facilities that are anywhere from 60 to over 200 miles away. Recently they have been expanding to critical access hospitals in rural communities that have 25 beds or less where the e-ICU would monitor one bed.

Currently the e-ICU monitors 70 beds in 4 states.

Part of the hospital systems mission is to keep patients in community as much as possible. For example, if flying a patient 200 miles to the large tertiary facility costs $10000, however with the e-ICU there is the opportunity to stop some of those transfers, which saves money. There are currently 16 of these critical care access hospitals that have one bed where the e-ICU is set up to monitor the patient.

Staffing:

Nurses:
- There is 24-hour nursing coverage
- All nurses work that work in the e-ICU actually work in the local tertiary care facility and the nurse is scheduled to work either at the facility or in the e-ICU.
- The nurses that work in the e-ICU are selected through the interview process and have at least 2-3 years of CCRN or critical care experience.
- There is one nurse monitoring the beds for each shift.

Physicians:
- The e-ICU is staffed with physicians 20 hours a day from noon to 8 am.
- There are 3 full-time physicians that as a sideline do clinical work. The hospital is expecting to add 4\textsuperscript{th} full-time in July.
- Additionally there are other physicians that fill in
- All physicians are specialists in critical care medicine and board certified.

Where are the monitored beds (urban, rural)?
- The e-ICU monitors 3 community hospitals, which are located in cities ranging from 20,000 to 40,000 people
Conversely the e-ICU monitors single beds in facilities that have fewer than 25 beds with town populations between 1000 - 5000 people. This creates a unique opportunity where physicians from other specialties “come and see patients” via telemedicine.

**Is there any special continuing training for e-ICU personnel?**

The hospital system is currently waiting to add 9 1-bed facilities, which takes approximately 3 months to complete.

The issue is that in each state they are practicing the intensivist has to pass state credentialing which is a “huge challenge, very complex and convoluted.”

The nurses have a little bit easier time because there is currently a nursing compact in three on the states that will accept the home state licensure.

**How is the e-ICU working out for your hospital system?**

“It is awesome. There have been wonderful outcomes” including: an APACHE retrospective study, which looked at pre-ICU and post –ICU scores, which predicted 30% mortality and the actual was much lower and 15%. That has even decreased more.

Additionally, the length of stay in the ICU has decreased by one-third and is one day shorter than predicted.

The implementation of the e-ICU has helped to lower the number of transfers from critical access facilities. In some places believe, the hospital system believes that 85% of the patients kept would have been transferred prior to the e-ICU.

“The technology works and the model works.”

**What are the most and least useful things you have found with the e-ICU system?**

**Most:**

- The participant believes that the e-ICU can be a support 24 hours a day. When practicing at small facility, there is usually a nurse 24 hours a day but there might not be a physician, so at 11:30 pm physician is at home and the nurse use to have to decide “should I wake up the doctor?” Now that nurse can call the e-ICU and get support.
Least:
- The participant says that there are some resisters out there to the use of the e-ICU technology. It is an issue for the e-ICU when they have to call someone that might resist.

Aside:
The e-ICU has 3 levels of intervention that each physician can give to their patient. Those range from a level 1 meaning the e-ICU can only intervene in a crisis, or best practice to a level 3 meaning the e-ICU can intervene at any time. Over time they have seen a decrease in the number of level 1s and surgeons tend to be level 1 where pulmonologists tend to be level 3 because they “just don’t want to be awakened at night.”

What about the e-ICU have been surprising to you after implementation?
The participant believes that one area where the e-ICU didn’t do well in when transitioning to the use of the e-ICU partially because of constant change. The participant has been reading about change management and felt that they should have done a better job developing the urgency of a need. Most people are not going to just trust something new without use first, as a result the e-ICU didn’t have the support at the local places initially, underestimating change and over estimating usage.

The participant was also surprised by the resister problem where, some of the people the participant can tell by their personalities that the e-ICU might be a struggle to gain buy-in, but every once in a while someone comes out of the blue is adamant about not letting the e-ICU help with patient care.

Additionally, the participant believed in a “naive notion” that if the physician called from the e-ICU, the participant thought it would be a collegial interaction with the ICU physician, however this turned out to not be the case.

The participant didn’t expect to get as good of results as they actually saw after implementation. The outcomes have been more dramatic at the tertiary facility than what they expected.

What do you see as the unrealized potential of the e-ICU or what opportunities do you see it being used for in the future?
The hospital system has taken this as an opportunity to have tertiary access to specialist and as a way to develop protocols. In some of the smaller facilities there
may not be a pharmacist so they are working to develop a protocol for drug administration and pharmaceutical intervention via the e-ICU (e-pharmacy).

The participant additionally thinks that the e-ICU technology in the NICU or PICU and help stabilize the patient until flight crew gets there.

The participant also sees a use for stroke care and that the e-ICU has the opportunity to do a lot more with the initial stroke care in the smaller facilities. The smaller facilities may not have a CAT scan or anyone to read it, especially since part of the stroke care plan is to get care to the patient within a certain time.

The participant can see a use it in the emergency department, especially in case where the ED might be staffed by NP or PA. Additionally what can do to strengthen the ER response? The key is having access to the specialist.

For example, last year there was a large blizzard and a small child that got caught outside in the blizzard. The child was in a rural location and when it was finally found and brought into the critical access hospital the child had a temperature of 80 degrees. As a result of the blizzard, the patient was not able to be transferred from the smaller facility to the tertiary facility. In this case, the e-ICU actually brought in a pediatrician to interact and help with the patient care for the child at the small facility until the blizzard subsided and they were able to transport the child to the smaller facility. So they would bring in experts in the area if needed, especially for things like infectious disease (e.g. at least it might be a phone consult).

Aside:
Dr Zawada the medical director has published about 2 years ago about outcomes maybe in Chest or American health or JAMA.

The e-ICU has been very well received by the patients. The patients will wave at the e-ICU when the camera turns on. Additionally, the people in the e-ICU will talk with the patients, however they only have 1 way video. In fact, one gentleman that was a patient put on a mask for Halloween and hit the call button.
Participant D.

The e-ICU characteristics:

The e-ICU covers 75 beds. The ICU beds are in both surgical and medical units, and private and more academic organizations. Patients are in 3 urban hospitals and has been in operations for almost 5 years. When the transitioned to using the e-ICU they also transitioned to an EMR and currently the hospital systems that they are working with don’t yet have comprehensive EMR in the rest of the system, just in ICU.

Staffing

Nurses:
- There are two nursing shifts from 11 am to 11 pm and 7 pm to 7 am (1 nurse each shift).
- Most of the nurses that staff the e-ICU have been intensive care nurses for 5 years or more.

Physicians:
- There is one board certified intensivist in the e-ICU from 7 pm to 7 am.

Where are the monitored beds (urban, rural)?

All of the beds monitored in this e-ICU are in urban hospitals.

Is there any special continuing training for e-ICU personnel?

Ongoing standard kinds of in services.

How does the e-ICU interact with other computer programs that your hospital uses?

(See below, when the participants talks about interface among computer systems this is what is referred to).

How is the e-ICU working out for your hospital system?

The use of the e-ICU is working “very well seen improved severity adjusted outcome score.” This is done by comparing like patients to like patients in units that have the e-ICU as compared to those that don’t.)
The participant goes on to talk about the history of the e-ICU implementation in which all three facilities were brought “online” almost simultaneously. Each of the hospitals was very different in one the nursing staff was very accepting of the e-ICU whereas the physicians were resistant, one the physicians were very accepting of the e-ICU whereas the nursing staff was resistant, and one both the physicians and nurses were very accepting. Where both were engaged, the e-ICU implementation had almost immediate improvements to patient outcomes, whereas limited or no improvements where seen in the other two. After training and working with the nurses in the nursing hesitant hospital, the e-ICU gained the nurse’s acceptance after which improvements were seen. Finally the hospital with hesitant physicians, has still been struggling to gain e-ICU acceptance and there they have tended not to see improvements. Thus, “we had an interesting history.”

What are the most and least useful things you have found out about it?

Most useful:
- “I think it varies.”
- There seems to be a tighter integration at the bedside between nurses and physicians, Because the notes are electronically available to everyone they are more transparent and tend to be more consistently maintained.
- It is especially useful at night when there is an experienced intensivist looking at patients rather than the on-call physician that may have insufficient information to make an accurate decision. It is also nice because now there is expertise available around the clock.
- Smart alerts and alarms help patients to be on top of things and improved standard of care.

Least:
- Sometime the documentation can be unwieldy
- Additionally, the interface design is a little cumbersome especially when compared with other vendors (e.g. medical record vendors may have robust electronic note that works on the floor, but does not work with the EMR of VISICU, so basically you have to double or triple enter information. Software compatibility issues.)
- The participant alludes to the “Best in breed” (The participant feels means that it may be really good in the specific thing but when your try to apply it to something else or expand the capability it may be at first monolithic.)

What about the e-ICU have been surprising after implementation?
The e-ICU to the participant is a very different way of handling patient care. In the participant’s experience as a practicing intensivist, the participant feels removed from the patient care while in the e-ICU. Additionally, there are extraneous factors that being removed creates difficulty in interactions with bedside, difficulty in getting point across, and how at the bedside, they see you as a camera and how that changes the interaction. (e.g. might have the same type of issues as text messaging or even phone conversations.)

The amount of how to plan for when the e-ICU intensivist might not know the bedside physician and various factors that may help people work together in a coordinated effort of patient care.

**What do you see as the unrealized potential of the e-ICU? Or, what opportunities do you see the e-ICU being used for in the future?**

The participant believed that e-ICU is something that will get integrated to a greater degree within the hospital system. This is for a number of reasons including: there are fewer intensivists coming out of school and telemedicine is a way to spread this resource out over time and space. The participant also sees widespread adoption as inevitable.

The participant believes that the technology will be expanded to work for other venues, like the ED or “buffers” where patients are staying (e.g. patients that should potentially be in the ICU but aren’t due to overcrowding).

The participant believe that the technology that is standard in the e-ICU will be improved and become more sophisticated, like 2 way video and better audio.

The participant believes that the supportive software detection algorithms and early alert algorithms will expand or in the participant’s words the “intelligence in supportive software will grow”. This will facilitate more rapid cue detection by a nurse or physician when alerted by the software. The participant cited the financial industry’s computer software as a model for further improvements in terms of “computer smarts” for the e-ICU.

Finally, the participant believes that there will be a greater emphasis on data visualization. For example, the EMR currently contains basic patient information, which is represented as single data elements graphed over time. A data visualization of a more integrated human system, that involves taking that textual format and turning it into a much more visual representation. Within these representations, most likely designers will try to group things appropriately, but not always right. In
addition, the participant believes that there will be an increased ability for the nurse or physician to explore the graphical representation.