1-1-2010

Investigating The Impact Of Process Complexity On Quality Of Care In Hospital Emergency Departments

Laura Carolyn Ruff

INVESTIGATING THE IMPACT OF PROCESS COMPLEXITY ON QUALITY OF

CARE IN HOSPITAL EMERGENCY DEPARTMENTS

By

Laura Carolyn Ruff

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Industrial Engineering
in the Department of Industrial and Systems Engineering

Mississippi State, Mississippi

December 2010

INVESTIGATING THE IMPACT OF PROCESS COMPLEXITY ON QUALITY OF CARE IN HOSPITAL EMERGENCY DEPARTMENTS

By

Laura Carolyn Ruff

Approved:

Lesley Strawderman
Assistant Professor of Industrial and Systems Engineering
(Director of Thesis)

Allen Greenwood
Professor of Industrial and Systems Engineering
(Committee Member)

Kari Babski-Reeves
Associate Professor of Industrial and Systems Engineering
(Committee Member)

Sarah Rajala
Dean of the Bagley College of Engineering

John Usher
Professor and Graduate Coordinator of Industrial and Systems Engineering

Name: Laura Carolyn Ruff

Date of Degree: December 10, 2010

Institution: Mississippi State University

Major Field: Industrial and Systems Engineering

Major Professor: Dr. Lesley Strawderman

Title of Study: INVESTIGATING THE IMPACT OF PROCESS COMPLEXITY ON QUALITY OF CARE IN HOSPITAL EMERGENCY DEPARTMENTS

Pages in Study: 77

Candidate for Degree of Master of Science

This research examined the impact of ED process complexity on hospital quality outcomes. Nine emergency department nurse managers from hospitals in Mississippi, Alabama, and Louisiana were interviewed regarding processes of registration, laboratory testing, medication administration, radiology, and discharge. Interview data was coded according to variables in proposed equations for patient-focused, provider-focused, and overall process complexity. Hospital quality was measured using existing process of care, outcome of care, and patient satisfaction standards. Results showed a strong negative correlation between process complexity and overall quality, suggesting that hospitals with lower process complexity experience higher quality outcomes. Regression analysis showed that the average number of patient steps in a process and the overall complexity the registration process were significant predictors of overall quality. Methods of reducing patient steps and registration process complexity are discussed.

Keywords: healthcare quality, process complexity, emergency departments

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Background

Emergency departments (EDs) are a vital component of the U.S. healthcare system. EDs provide initial treatment for a wide variety of medical conditions, some of which are life-threatening and require immediate attention. From 1996 through 2006, annual ED visits in the U.S. increased from 90 million to over 119 million, a 32% increase over ten years. A rise in patient demand has been coupled with a decrease in the number of U.S. EDs, further increasing the demand per facility. Recent statistics also show that the south has approximately 5% higher ED utilization rates in comparison to other regions (Pitts et al., 2008). Many EDs have not been able to accommodate this increase in demand with available capacity, thus crowding, ambulance diversion, and patient displacement in emergency care have become a major concern of the nation's public health entities. An Institute of Medicine report revealed that many overburdened EDs regularly operate beyond their intended capacity at the risk of providing sub-optimal care (Committee on the Future of Emergency Care in the United States Health System, 2007).

Crowding is one of many challenges facing EDs. Normal ED operations are characterized by a great deal of complexity; arrival rates are highly unpredictable, patient acuity varies widely, and task priorities must continuously be shifted to accommodate the most critical patient need. The wide range of services provided and the time pressures characteristic of emergency care also contribute to the complexity of ED operations. Every patient entering the ED must undergo a series of administrative, diagnostic, and treatment processes before being discharged or admitted for further care. All of these ED processes are characterized by many interactions between patients and personnel, many administrative and clinical tasks, and large volumes of information. Processes that take place beyond the ED itself, such as those involving collaboration with hospital imaging and laboratory departments, require an even larger amount of coordination of personnel, resources, and information.

The measurement and reporting of healthcare quality is prevalent in the United States. While quality measures of healthcare were traditionally based on mortality and readmission rates, process of care guidelines and patient satisfaction measures have been added to the growing list of standards used by hospitals for benchmarking, accreditation, reimbursement, and consumer information purposes. Research has shown that emergency departments generate high rates of preventable adverse events, risk management claims, and patient complaints (France, 2006), making them an appropriate arena for quality improvement efforts in healthcare. Recent patient safety initiatives such as "The 5 Million Lives Campaign" sponsored by The Institute for Healthcare Improvement (IHI) have emphasized the need to protect patients from incidents of medical harm (Institute for Healthcare Improvement, 2010).

Problem Statement

Complexity is a primary focus of systems and safety research, as it has been identified as one of the major determinants of susceptibility of high-risk systems to accidents (Perrow, 1999; Woods & Cook, 2001). The fields of nuclear power and aviation have learned at great cost that the underlying complexity of operations contributes to failures in human performance (Woods, 2000). The link between complexity and human errors has also been established in healthcare research aimed at improving patient safety (Fraass, 1998; Strong, 1999; Hinckley, 1995). Thus, complexity reduction has been targeted as a goal of leading patient safety experts (Nolan, 2000; Woods & Cook, 2002).

In addition to implications of complexity's effect on clinical healthcare quality, evidence also suggests that complexity has a negative effect on service quality in healthcare settings. The enhanced role of patients as informed consumers, active contributors, and evaluators in their medical care is linked to increased complexity that leads consumers to take short-cuts in decision making, potentially resulting in sub-optimal care (Hibbard, 2003). Evidence also suggests that complexity arising from the number of providers encountered within a visit may have a negative impact on patient satisfaction (Strawderman & Salehi, 2009). Other industries, including retail and the automotive industry, have successfully managed to reduce complexity experienced by consumers in efforts to create more satisfied customers (Rouse, 2008).

While emergency department processes are inherently complex, predictable and, to some extent, controllable factors of workflow, scheduling, and information availability contribute to the complexity experienced by patients and providers in this environment.

Despite evidence of the negative effects of complexity on provider performance and the patient experience, a specific link between complexity in emergency departments and the quality of care that patients receive has not been established. Complexity should be examined from both a patient-focused and provider-focused standpoint in order to better understand its impact on clinical and service dimensions of quality. This research seeks to examine the impact of process complexity in emergency departments on the quality of care that hospitals provide, as measured by existing process of care, outcome of care, and patient satisfaction standards.

Objectives of the Study

The objectives of this study were to develop a metric for provider-focused and patient-focused complexity in hospital emergency department processes, determine whether there is a relationship between process complexity and the quality of care hospitals provide, and identify factors for reducing complexity to improve provider performance and the patient experience. Specific hypotheses include:

1. Process complexity and overall hospital quality are negatively correlated. Higher process complexity results in lower overall quality scores.
2. Patient-focused complexity and patient satisfaction are negatively correlated. Higher patient-focused complexity results in lower patient satisfaction.

3. Provider-focused complexity and process-of-care quality are negatively correlated. Higher provider-focused complexity results in lower process-of-care quality.

Scope and Limitations

This study analyzes the quality of healthcare provided by hospitals in three states: Mississippi, Alabama, and Louisiana. Quality data was collected from a database of publicly available hospital comparisons. Hospitals are not required to participate in this reporting system; therefore, some emergency departments in the region were excluded from the study due to lack of data. This study is exploratory; thus, complexity data was collected from a small number of hospitals. This data was extracted from recordings of process descriptions provided by administrative nursing staff in semi-structured interviews. Therefore, the accuracy of complexity data is dependent on the respondent and their knowledge of processes in the ED for which they provided data.

CHAPTER II

LITERATURE REVIEW

Complexity in Healthcare Systems

Healthcare systems have been defined as complex adaptive systems characterized by uncertainty, conflicting interests, and rapid change. As such, they pose unique challenges for optimal design and management (Rouse, 2008). In contrast to a traditional mechanistic system, complex adaptive systems are comprised of human "agents" that interact in a nonlinear and unpredictable fashion. Agents learn and adapt to cope with internal and external environmental demands, resulting in self-organization and emergence of new system properties. Interactions and information exchanges take place beyond system boundaries; thus, complex adaptive systems tend to co-evolve with their environment (Anderson, Crabtree, Steele, & McDaniel, 2005). As they evolve, complex adaptive systems become increasingly complex.

The growth in complexity of healthcare systems can be attributed to a number of factors, including the trend towards centralized hospital systems rather than independent providers and the trend towards patient centered care. These trends have impacted the complexity experienced by both patients and care providers within healthcare systems.

The trend towards patient centered care has emphasized the role of informed choice of healthcare consumers. Advocates of informed healthcare consumers assume that, if consumers use comparative performance information in choosing healthcare services, providers will be motivated to improve the quality of their medical care. Consumer roles of "coproducer," in which patients actively contribute to decisions regarding medical treatment and "evaluator," in which patients critique the care received by providers, have also been suggested as a means of bringing about change within the health care sector. Hibbard (2003) acknowledges that enhanced roles of consumers in healthcare involve "burdensome" decision-making tasks. When faced with too much information or decisions involving multiple variables and trade-offs, consumers engage in "short-cut" strategies to reduce complexity and cognitive burden. (Hibbard, 2003). Thus, patient-focused complexity arising from the enhanced role of consumers in health care has the potential to reduce patient satisfaction and result in sub-optimal care.

Patient-focused complexity has also grown as a result of the trend towards centralized healthcare systems. Current evidence in research suggests that the complexity inducing trend toward centralized healthcare systems has been driven by a desire for market dominance rather than patient care and quality (Cuellar & Gertler, 2005). Rather than visiting a small private clinic of general practitioners or specialists, patients often must navigate large health complexes and receive care from multiple departments and providers in order to receive basic health services today (Barr, 1995). As healthcare organizations have grown in size, the complexity of the processes therein has increased, requiring coordination of a larger number of entities. The work of providers is characterized by a multitude of administrative tasks in addition to clinical tasks, and care is coordinated with professionals across many disciplines (Plsek, 2001). Increased implementation of automated systems intended to increase efficiency within healthcare systems has also contributed to provider-focused complexity. On a regular basis, providers must learn and adapt to new technology that often is more of a burden than an enabler (Ball & Bierstock, 2007). Thus, both patient-focused and provider-focused complexities are issues for concern in today's healthcare systems.

Although complexity is a property that is inherent and beneficial to modern organizations (Meadows, 2008), human factors principles suggest that complexity should be tamed to improve human performance in complex systems (Woods, 2000). Using other markets as benchmarks, it has been suggested that a goal of healthcare should be to "increase the complexity of healthcare where it can be managed in order to reduce complexity for patients, their families, physicians, nurses, and other clinicians" (Rouse, 2008). In the retail market, for example, the consumer is aware of only a small portion of the complexity involved in making a large variety of products and services available for purchase. Figure 1.1 depicts the comparative levels of consumer complexity to total market complexity, as measured in information bits, for five markets, suggesting that the health care industry is a poor performer in reducing complexity experienced by consumers (Rouse, 2008).

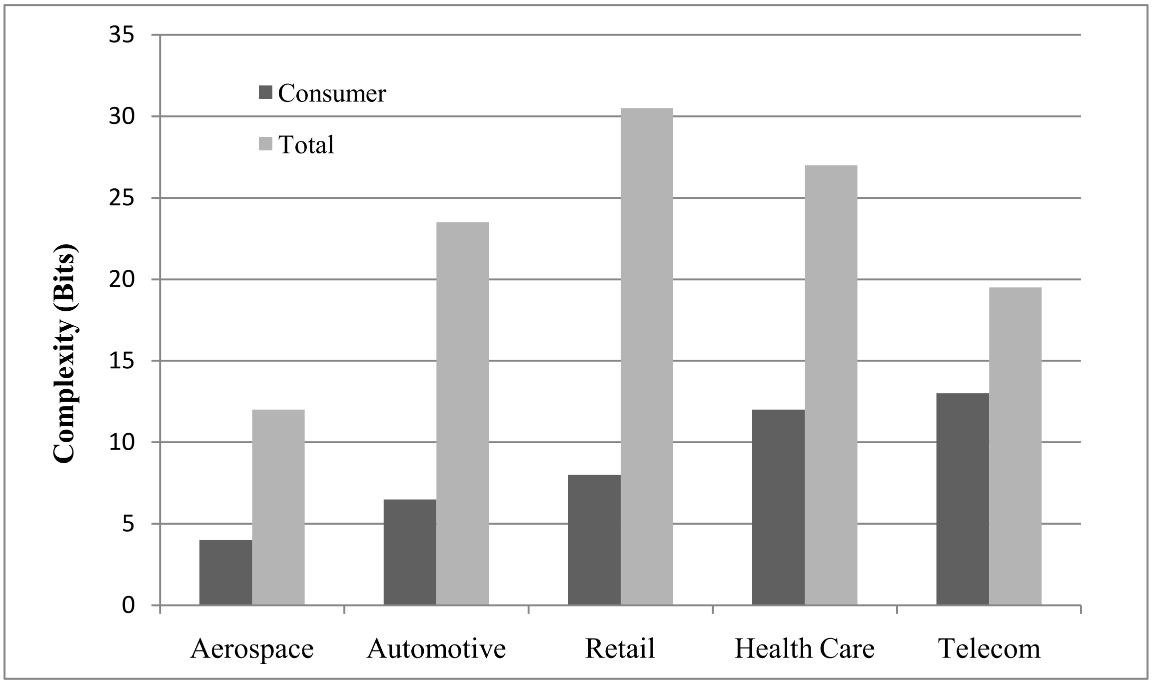

Figure 1.1 Comparison of consumer and total complexity in various markets

Complexity and System Performance

Complexity has been defined as a "fundamental but abstract property of socio-technical (i.e., man-machine) systems that represents the expense or consequence of increased system functionality, efficiency, or flexibility" (France, 2006; Moses, 2003). Complexity is a primary focus of systems and safety research, as it has been identified as one of the major determinants of susceptibility of high-risk systems to accidents (Perrow, 1999; Woods & Cook, 2001).

Healthcare systems research has established the link between complexity and medical errors (Fraass, 1998; Strong, 1999; Hinckley, 2003). Thus, complexity reduction has been targeted as a goal of leading patient safety experts (Nolan, 2000; Woods & Cook, 2001). Complexities in patient factors, work process factors, and ED-hospital interface factors have been acknowledged for their effect on provider and system performance in EDs, but traditional measures of ED system performance have focused on crowding and ambulance diversion (Solberg, 2003).

Experts have suggested that the simplification of healthcare systems will improve their "reliability and resilience," and that tools and resources to help practitioners cope with complexity are a necessity in improving quality of care (Woods & Cook, 2001). Leape presented sources of complexity present in the proliferation of choices arising from non-therapeutic differences in drug doses and times of administration, different locations of resuscitation equipment within different units, and different methods for the same surgical dressings, all of which can be readily removed (Leape, 1994).

Complexity Measurement

Despite recognition of complexity's impact on healthcare system performance, there is a minimal amount of literature that addresses the measurement and analysis of process or system complexity within healthcare systems. Rather, complexity is largely used as a measure of care requirements indicative of patient severity, often referred to as "case complexity." The attempt to arrive at a valid measure of complexity as it pertains to patient care processes in EDs uncovered a wide range of concepts relating to complexity.

Horgan (1995) points out the lack of a "unified theory" of complexity in his discussion of thirty-one varying definitions of complexity. Informally, the term *complex* can be synonymous with complicated, difficult to understand and explain, or strictly just *large*. From a scientific standpoint, complexity is often used to describe the degree of entropy or randomness within a system. Adami distinguishes between several approaches to define and measure complexity: computational vs. statistical, structural vs. functional, sequential, and hierarchical, among others (Bullock, 2004).

Workflow Complexity Measurement

The field of software engineering has utilized complexity metrics to predict readability, reliability, and maintainability in the design phase of software development (Buse, 2008). Complexity metrics have been useful in reducing software maintenance costs by quantifying the ease or difficulty with which a program module may be understood. Adaptations of these metrics have been applied to measure complexity of workflow in business process models (Cardoso, 2006). Cardoso (2006) describes an organization's workflow as an ordered group of business activities undertaken by an organization to achieve a goal that, like a complex system, exhibit properties of nonlinearity and interdependence. The author defines the "control-flow complexity (CFC)" of a process as the accumulation of splits, joins, and loops in a process flow diagram. Equation 2-1 shows the formula for control-flow complexity of a process (P).

$$CFC(P) = \sum_{i \in (XOR-splits\ of\ P)} CFC_{XOR-split}(i) + \sum_{j \in (OR-splits\ of\ P)} CFC_{OR-split}(j) + \sum_{k \in (AND-splits\ of\ P)} CFC_{AND-split}(k) \quad (2\text{-}1)$$

The function CFC(P) is computed based on the individual control-flow complexity of XOR, OR, and AND-splits in a process. A higher value of CFC(P) denotes greater overall architectural complexity of a process (Cardoso, 2006).

Task Complexity Measurement

Complexity has been more widely studied in regards to specific tasks or activities that comprise processes and workflow within organizations. Varying definitions of task complexity exist. For example, complexity has been measured as the number of decision alternatives for a multiple-choice task (Payne, 1976), the number of different fault types for an inspection task (Galloway &Drury, 1986), and the number of channels to be monitored for a monitoring task (Kennedy & Coulter, 1975). These definitions of complexity are more suited for well-defined tasks in an experimental setting, as tasks in actual work environments are difficult to classify as purely multiple-choice, inspection, or monitoring tasks. Nolan summarized more general definitions of task complexity as: steps in the task, number of choices, duration of execution, information content, and patterns of intervening, distracting tasks (Nolan, 2000).

Hinckley (2003) measured complexity in assembly tasks as the total assembly time (TAT) minus a constant "c" multiplied by the number of operations (TOP), or steps, in the task. Figure 1.2 illustrates the rise in defects in manufactured equipment as their assembly processes grew in complexity.

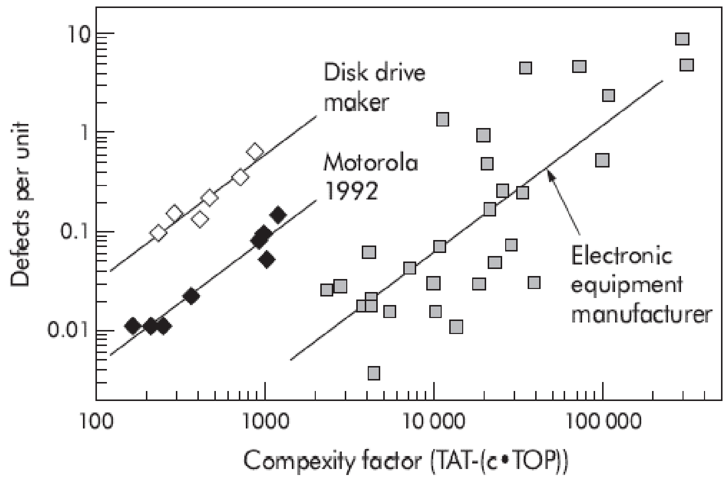

Figure 1.2 Manufacturing complexity and defects

The author acknowledges this measure of complexity as "the best measure of product and process complexity over a wide variety of conditions." However, efforts to predict defect rates of a combined set of processes, each with its own complexity measure, were admittedly poor matches to observed performance (Hinckley, 2003). Other researchers have confirmed the link between the duration of care and adverse events in healthcare. Patient records contain information about length of stay and time spent in various treatment stages in the ED, but time estimates for specific tasks in the treatment process (e.g. medication administration, specimen collection) are difficult to collect (Hinckley, 2003).

System Complexity Measurement

Information theory has been applied to quantify manufacturing system complexity, with emphasis on the uncertainty of demands on system resources (Calinescu, Efstathiou, Sivadasan, Schirn, & Huaccho, 2000). France et al. proposed a modified version of this measure for use in EDs with the addition of a workload component of complexity (France, 2006). This measure has been suggested as an indicator for safe capacity in emergency departments, as overcrowding has become an issue responsible for ambulance diversion, long patient waits, frustration for patients and ED personnel, and greater risks for adverse events (Solberg, 2003), all of which could ultimately affect quality outcomes within EDs. Unlike measures of workflow or task complexity, the system complexity measure proposed by France has both static and dynamic components. Static complexity is dictated by work processes; thus, it can be planned and predicted. Dynamic complexity, however, changes in accordance with demands on the system. By measuring change and uncertainty in work patterns, the authors suggest that this measure of complexity is more adept than traditional workload and crowding measures at determining whether ED resources (physicians, nurses, technicians, etc.) are operating within their safe capacity (France, 2006). Monitoring each resource within the ED to arrive at a cumulative value of system complexity is a very data intensive approach, and there have been no documented attempts to capture ED complexity as a real time measure of system state.

Healthcare Quality Measurement

Quality measurement has been a part of the U.S. healthcare system since the early 1900s, beginning with the founding of the American College of Surgeons (ACS) to address variations in the competency of medical professionals (Roberts, 1987). A model presented by Donabedian in the 1980s suggested that healthcare quality measurement should include three dimensions: structural health system characteristics, processes of interaction between clinicians and patients, and outcomes of care that reflect patients' health status (Donabedian, 1988). This model has become the basis for many healthcare quality improvement endeavors and is still widely applied today.

Although quality measurement has long been a part of healthcare systems, recent initiatives have created awareness surrounding shortcomings in quality of care in the U.S.. Patient safety became a leading concern when the 1999 Institute of Medicine Report "To Err is Human" shed light on the prevalence of medical errors. According to the IOM report, the healthcare system itself was between the fifth and ninth leading cause of death in the country. Since that time, clinical quality measurement has become increasingly prevalent in efforts to improve patient safety in the nation's hospitals (Kohn, Corrigan, & Donaldson, 2000).

The prevalence of clinical quality measurement and reporting was solidified by Section 501(b) of the Medicare Prescription Drug, Improvement and Modernization Act of 2003, which established an incentive payment for hospitals that elected to report on an initial set of ten quality performance measures and agreed to have their data publicly displayed. These measures address how often hospitals give recommended treatments known to get the best results for patients with certain medical conditions (heart attack, heart failure, pneumonia, children's asthma) or surgical procedures. Scores are derived from relevant patient discharge records. Initially, almost all hospitals eligible for the payment incentive provided data for the ten "starter set" measures, reflecting care delivered during 2004 (U.S. Department of Health and Human Services, 2010).

The majority of acute care hospitals participating in public reporting for incentive payment have voluntarily provided annual data on additional clinical process measures that have been identified by the Hospital Quality Alliance (HQA). The HQA is a public-private collaboration of various stakeholders in the healthcare industry with the mission of encouraging hospitals to collect and report quality data. Members include the Center for Medicare & Medicaid Services (CMS), the Joint Commission on Accreditation of Healthcare Organizations (JCAHO), American Medical Association (AHA), American Hospital Association (AHA), and numerous others. The complete set of clinical process measures, also referred to as "process of care measures," promoted by the HQA currently consists of 28 measures.

In addition to the increase in attention to clinical quality measurement, consumer perceptions of healthcare have become increasingly valued by healthcare providers and policymakers. Thus, service quality has been acknowledged as a necessary dimension of healthcare quality, and the Hospital Consumer Assessment of Healthcare Providers & Systems (HCAHPS), developed in 2002, remains a widely used tool for evaluating patient satisfaction with healthcare services (Hospital Consumer Assessment of Healthcare Providers and Systems, 2010).

Public reporting of both clinical and service quality in healthcare was achieved through joint efforts between the CMS and other HQA members. An online tool was created that allows consumers to compare hospital quality for the 28 HQA process of care measures, along with selected patient satisfaction measures from HCAHPS and outcome of care measures from mortality and readmission rates. All of the reported quality measures are endorsed by the National Quality Foundation (NQF). The web-based tool titled "Hospital Compare" is available at http://www.hospitalcompare.hhs.gov. It was intended, in part, to create more informed healthcare consumers. The tool is also a reliable source of data for professionals (U.S. Department of Health and Human Services, 2010).

Summary

Complexity is an inherent property of healthcare processes, yet evidence suggests that it should be tamed to increase both clinical and service quality in healthcare systems. Research has shown that complexity makes providers more susceptible to medical errors, posing a threat to patient safety. Complexity arising from enhanced roles of healthcare consumers has been shown to result in short-cuts in decision making by consumers that potentially undermine their own interests. Patient satisfaction has also been suggested as a potential trade-off in high complexity healthcare environments.

Though complexity is a widely discussed topic in healthcare literature, few empirical studies have attempted to quantify complexity of healthcare processes or systems. Proposed complexity measures have been adapted from software engineering and business process modeling, but there is no previously validated metric for healthcare process complexity.

Quality measurement has become increasingly prevalent in U.S. healthcare, and joint efforts from the CMS and HQA have made the abundance of quality data publicly available to consumers via the Hospital Compare tool. This data provides a comprehensive view of healthcare quality with consideration of performance along process of care, outcome of care, and patient satisfaction standards. This study will utilize this source of existing quality data in investigating the relationship between process complexity and quality of care in hospital EDs.

CHAPTER III

METHODOLOGY

Experimental Overview

This study was designed to investigate the relationship between ED process complexity and hospital quality. Nine hospitals with connected EDs were studied. Complexity data was obtained through semi-structured interviews with a single ED administrative nursing staff member at each hospital. Existing quality data for the nine hospitals was collected through the Hospital Compare tool described in the previous chapter. A summary of the variables defined for each hospital is provided in Table 3.1.

Table 3.1

Experimental Variables

Independent Variables		**Dependent Variables**	
Name	**Definition**	**Name**	**Definition**
Overall complexity	Equation 3-5	Overall quality	Average of all 26 quality measures
Patient-focused complexity	Equation 3-2	Patient satisfaction	Average of 10 patient satisfaction measures
Provider-focused complexity	Equation 3-4	Process of care quality	Average of 12 process of care quality measures

Independent Variables

Overall, patient-focused, and provider-focused complexity were measured by analyzing five "core" processes in the ED: patient registration, medication administration, blood sample testing, X-ray imaging, and patient discharge. Details on each of the five processes are shown in Table 3.2.

Table 3.2

Selected ED Processes

ED Process Name	**Process Start**	**Process Stop**
Patient registration	Patient arrives at ED	Clerk completes information retrieval
Medication administration	Physician orders medication	Nurse administers medication
Blood sample testing	Physician orders blood test	Physician receives test results
X-ray imaging	Physician orders X-ray	Physician receives image results
Patient discharge	Physician issues medical clearance	Patient exits ED

The five processes in Table 3.2 represent processes that are common to operations in any ED. Additional "core" processes involving treatment procedures were excluded from analyses because the steps, decision points, and duration of these processes are highly dependent on the presenting condition of the patient. Registration processes may differ according to patient acuity, as registration of patients arriving by ambulance must be handled differently than registration of ambulatory (i.e. "walk-in") patients. For the purposes of this study, the registration process was measured for ambulatory patients only. Aside from this distinction, the flow of patients in the five chosen processes should not be dependent on patient condition. These processes were intended to represent varying levels of complexity depending on how they are performed differently from hospital to hospital. Preliminary process diagrams created to depict the generalized flow of these processes are given in Appendix F.

The five processes were investigated during semi-structured interviews, described in detail in Appendix B. Upon completion of the interview at each hospital, data was coded in terms of the complexity variables defined in the following section.

Patient-Focused Complexity

Equation 3-1 was used to calculate patient-focused complexity of each process at each hospital:

$$PAT_{ij} = \frac{1}{6}\left(\frac{PI_{ij}}{PI_{i,\max}} + \frac{SI_{ij}}{SI_{i,\max}} + \frac{RT_{ij}}{RT_{i,\max}} + \frac{DT_{ij}}{DT_{i,\max}} + \frac{IN_{ij}}{DT_{i,\max}} + \frac{PS_{ij}}{PS_{i,\max}}\right) \qquad (3\text{-}1)$$

where i = process index,

j = hospital index,

PAT = patient-focused complexity

PI = number of providers who interact with the patient,

SI = number of other staff who interact with the patient,

RT = number of room transitions,

DT = number of department transitions,

IN = number of information provision opportunities,

PS = number of steps involving patient,

and *max* denotes the maximum observed score for each variable from all data collected.

For example, PI_{11} represents the number of providers who interact with the patient during the registration process at hospital 1, and $PI_{1,max}$ represents the maximum observed number of providers who interact with the patient during the patient registration process at *all* hospitals. Resulting scores for PI_{ij} will range from 0 to 1.

The variables in this equation represent aspects of a process that may contribute to the complexity of a patient's ED visit. The weight of each of the variables on the resulting complexity score was assumed to be equal. The number of providers who interact with the patient, *PI*, and the number of other staff who interact with the patient, *SI*, are important from a continuity of care standpoint. Patients are likely to experience less complexity when they interact with fewer staff and providers. The number of room transitions, *RT*, and department transitions, *DT*, also contribute to complexity experienced by patients as they have to travel or navigate through the ED and connecting departments (e.g. for an X-ray or lab tests) to receive treatment. The number of information provision opportunities, *IN*, represents the number of times a patient must relay medical history, insurance information, and other personal information. *IN* may also include steps involving evaluation of care during the ED visit. The total number of steps the patient processes through, *PS*, is a general representative of process complexity from the patient perspective.

Patient-focused complexity of each five processes (e.g. PAT_{11}, PAT_{21}, …, PAT_{51}) was averaged to determine the patient-focused complexity score for each hospital, PAT_j, as shown in Equation 3. Each hospital's patient-focused complexity score ranged from 0 to 1.

$$PAT_j = \frac{\sum_{i=1}^{5} PAT_{ij}}{5} \tag{3-2}$$

Provider-Focused Complexity

The formula for calculating provider-focused complexity of each process at each hospital is shown in Equation 4.

$$PRO_{ij} = \frac{1}{6}\left(\frac{PE_{ij}}{PE_{i,\max}} + \frac{PT_{ij}}{PT_{i,\max}} + \frac{IT_{ij}}{IT_{i,\max}} + \frac{CD_{ij}}{CD_{i,\max}} + \frac{DP_{ij}}{DP_{i,\max}} + \frac{TS_{ij}}{TS_{i,\max}}\right) \tag{3-3}$$

where i = process index,

j = hospital index,

PRO = provider focused complexity

PE = number of personnel involved,

PT = number of steps involving travel,

IT = number of information transfers between personnel,

CD = number of patient care documentation steps,

DP = number of decision points,

TS = total number of process steps,

and *max* denotes the maximum observed score for each variable from all data collected.

For example, PE_{11} represents the number of personnel involved in the patient registration process at hospital 1, and $PE_{1,max}$ represents the maximum observed number of personnel involved in the patient registration process at *all* hospitals. Resulting scores for PRO_{ij} will range from 0 to 1.

Provider-focused complexity measures the complexity of each process from the provider perspective. The number of personnel, *PE*, includes providers and other staff involved in the process. *PT*, the number of steps requiring travel from personnel, measures the degree to which personnel have resources available at their disposal without being required to travel. Higher provider-focused complexity arises from interactions with a large number of personnel and many steps involving travel. Information transfers among personnel, *IT*, includes steps when patient care information must be relayed to other personnel (e.g. doctor notifies nurse of flagged order on patient chart). Steps involving hand-offs of information are susceptible to loss or distortion of information; thus, processes with more information transfer steps are more complex. Steps involving patient care documentation, *CD*, are representative of the administrative task workload of the process, which also contributes to provider-focused complexity. Decision points in the process, *DP*, and the total number of process steps, *TS*, are general measures of process complexity.

Provider-focused complexity of each five processes (e.g. PRO_{11}, PRO_{21}, …, PRO_{51}) was averaged to determine the provider-focused complexity of each hospital, PRO_j, as shown in Equation 5. Each hospital's provider-focused complexity score also ranged from 0 to 1.

$$PRO_j = \frac{\sum_{i=1}^{5} PRO_{ij}}{5} \tag{3-4}$$

Overall Complexity

The provider-focused and patient-focused scores were averaged to determine the overall complexity score, COM_j, for each hospital, as shown in Equation 3-5. This score also ranged from 0 to 1.

$$COM_j = \frac{PAT_j + PRO_j}{2} \tag{3-5}$$

Dependent Variables

Existing quality data available through Hospital Compare was used to measure overall quality, patient satisfaction, and process of care quality at each hospital studied. The Hospital Compare database is updated each quarter, and the data included in this study was from the third quarter of 2009. This database includes quality data from acute-care "general" hospitals in the U.S. that elected to participate in incentive payment for quality reporting. In order to maximize the number of hospitals with complete data that could be included in analysis, a number of quality measures with missing data were excluded from analysis (see Table 3.4 for a listing of excluded measures). Table 3.3 presents a description of the categories of quality measures reported by Hospital Compare and the number of measures from each category that were included in analysis. Scores for all of these measures are reported on a scale from 0 to 100. A detailed listing of the 44 measures reported by Hospital Compare, including those excluded from analysis due to missing data, can be found in Appendix A.

Table 3.3

Summary of Quality Measures

Type of Measure	Number of Measures	Description
Process of Care	12	Provision of recommended care for heart attack, heart failure, and pneumonia patients
Outcome of Care	4	Mortality and Readmission Rates
Patient Satisfaction	10	Patient perceptions of hospitals from HCAHPS survey

Participants

Due to the exploratory nature of this study, a small sample of hospitals was chosen for analysis. Hospitals from Mississippi, Alabama, and Louisiana were considered for selection because these states are similar in population and other regional characteristics that could potentially affect hospital quality outcomes. Based on national comparisons, the Agency for Health Care Research and Quality ranks each of the three states in the "very weak" category for healthcare quality in acute care settings (Agency for Health Care Research and Quality, 2009). Among the three states of inclusion, hospitals were intentionally selected with varying overall quality, size (i.e. number of beds), and ED patient volume, in order to prevent these hospital characteristics from driving the results.

In order to select hospitals according to overall quality, a cluster analysis was performed to classify hospitals from the three states according to overall quality. A total of 296 hospitals from Mississippi, Alabama, and Louisiana participated in public reporting of quality measures for the third quarter of 2009. However, only 15 of these 296 hospitals provided complete data for all 44 quality measures. In order to increase the sample size of hospitals to be included in the cluster analysis, those measures with the most missing data were excluded from analysis. Table 4 lists the quality measures which were removed prior to analysis and the number of hospitals missing data for each. Complete descriptions of the measures can be found in Appendix A.

Table 3.4

Eliminated Quality Measures

Measure Name	**No. of hospitals missing data**
CAC-1	294
CAC-2	294
CAC-3	294
AMI-7A	238
SCIP-INF-4	211
AMI-8A	205
30-Day Readmission Rates for Heart Attack	175
30-Day Mortality Rates for Heart Attack	139
AMI-4	125
AMI-3	122
SCIP-INF-1	80
SCIP-INF-2	79
SCIP-INF-3	78
SCIP-VTE-2	78
SCIP-VTE-1	74
AMI-5	69
AMI-2	69
SCIP-INF-6	67

After eliminating 18 measures, 194 hospitals from Mississippi, Alabama, and Louisiana had complete data. The cluster analysis was performed on these 194 hospitals using the remaining 26 quality measures. Results of the cluster analysis showed three clusters of hospitals with similar quality characteristics. A minimum of two hospitals from each quality cluster were chosen for participation in the study.

Additional criteria considered for hospital selection were the number of hospital beds and the annual volume of ED visits. The selected hospitals within each quality cluster included one hospital from each quartile of a size criteria based on the number of beds and annual volume of ED visits among the 194 hospitals. Chosen hospitals fell within the same quartiles for both the number of beds and annual ED visits (e.g. first quartile of number of beds and first quartile of annual ED visits). An exception to these criteria was made for the hospitals selected from the third quality cluster. Because there were no hospitals within this cluster in the top two quartiles for both the number of hospital beds and annual ED volume, the hospitals that most nearly fit the criteria were substituted. Table 3.5 lists the selected hospitals and pertinent characteristics. Hospital names have been excluded to protect the privacy of the participants.

Table 3.5

Selected Hospitals and Criteria

Hospital	**State**	**Quality Cluster**	**Number of beds****	**Annual ED Visits****
1	LA	A	32	2204
2	MS	A	96	24081
6	MS	A	164	23910
4	AL	A	282	50785
5	MS	B	104	25518
3	LA	A	180	n/a
7	MS	C	95	1840
8	AL	C	99	11338
9	AL	C	173	17037

**Retrieved from http://health.usnews.com/best-hospitals

Interview Instrument Development

Prior to conducting interviews with the twelve hospitals, a subject matter expert (SME) with knowledge of ED operations was interviewed. The SME had previously worked as a nurse in acute care settings and is currently pursuing a Ph.D. in health informatics. Given her work and research experience with multiple hospitals in the region, this SME was helpful in estimating potential variations in the steps and procedures associated with the five ED processes of interest. Preliminary cross-functional process ("swim-lane") diagrams of the five processes (given in Appendix F) were presented to the subject with the goal of altering the diagrams to better suit the majority of hospitals. The draft interview instrument contained questions pertaining to labeled steps on these process diagrams (e.g. Which steps are listed under the wrong staff member's responsibility? Which steps require the patient to transfer rooms?) Given the large amount of variation in procedures that the SME had experienced from hospital to hospital, less reliance on pre-constructed process maps was suggested. As a result, a modified interview instrument was developed with a semi-structured style. Rather than having subjects describe how their ED's process differs from a baseline pre-constructed process map, participants will talk through the process and the interviewer will prompt the participant for more details as necessary. The modified interview script is included in Appendix B.

The second SME is a registered nurse manager in the emergency department at a local hospital. This SME participated in a full-length interview conducted with the instrument included in Appendix B. The pilot interview was used to test the effectiveness of the instrument. Following the interview, pilot interview data was coded to ensure that the necessary data could be extracted from the interview records for input into complexity equations. Data was extracted and no changes to the interview instrument were made; thus, pilot interview data was included in analysis.

Protocol

An administrative nursing staff member at each selected hospital was contacted for participation in the study. Following recruitment, semi-structured phone interviews were arranged for collection of complexity data. The interviews consisted of two parts. In part one, participants answered structured questions regarding hospital and ED characteristics. In part two, participants provided step-by-step descriptions of the five processes of interest. The interview script is included in Appendix B. Variations in process complexity among the hospitals were expected.

Data Analysis

Upon completion of interviews, data was coded to obtain scores for patient-focused, provider-focused, and overall complexity for each hospital (see equations 3-1 through 3-5). Raw data for each of the complexity variables is provided in Appendix E. Statistical analysis software (SAS version 9.2) was used in data analysis. Specific hypotheses included:

1. Process complexity and overall hospital quality are negatively correlated. Higher process complexity results in lower overall quality scores.

2. Patient-focused complexity and patient satisfaction are negatively correlated. Higher patient-focused complexity results in lower patient satisfaction.

3. Provider-focused complexity and process-of-care quality are negatively correlated. Higher provider-focused complexity results in lower process-of-care quality.

Pearson correlation coefficients were used to test these hypotheses. Pearson correlation coefficients and p-values for hypothesized relationships are reported.

Additional data analysis included the use of regression to develop a predictive model of hospital quality. Multiple regression analysis investigated the degree to which variables in patient-focused and provider-focused complexity (equations 3-1 and 3-3) explain variation in overall hospital quality. F-tests with an alpha level of 0.10 were used to determine model significance.

CHAPTER IV

RESULTS

Descriptive Statistics

Characteristics of the nine hospitals included in the study are shown in Table 4.1. Most participating hospitals were non-academic hospitals serving rural communities. The size of hospital EDs ranged from 5 to 31 beds. Participating hospitals varied in their use of information technology, particularly in the use of two popular information systems utilized by EDs: computerized physician order entry (CPOE) and electronic patient tracking systems (EPTS). CPOE allows physicians to place orders at bedside computers rather than handwriting orders on patient charts. CPOE then electronically transmits orders to medical staff and/or hospital departments responsible for completing orders. CPOE is advocated for speeding order processing, reducing errors in transcription, and providing error-checking features (e.g. medication interactions, order duplications) at the time of order entry (Kuperman & Gibson, 2003). EPTS, also referred to as "whiteboards," allow medical staff to track the location and status of ED patients. EPTS is advocated for improving communication among medical staff and assisting staff in moving patients through the ED as quickly as possible (Dietrich, 2010).

Table 4.1

Hospital Characteristics

Hospital	State	Type	Location	ED Beds	CPOE	EPTS
1	LA	Community	Urban	5	No	No
2	MS	Community	Rural	23	Yes	Yes
3	MS	Academic	Rural	24	Yes	Yes
4	AL	Community	Urban	31	No	No
6	MS	Community	Rural	10	No	Yes
5	LA	Community	Rural	10	No	No
7	MS	Community	Rural	4	No	No
8	AL	Community	Rural	9	Yes	Yes
9	AL	Community	Rural	10	No	No

Quality data for the nine hospitals was obtained from the Hospital Compare database. Descriptive statistics for the quality data is shown in Table 4.2. Mean overall quality scores ranged from 72.84 to 86.64. The mean overall quality score for the nine hospitals (μ=80.44) was slightly lower than the mean overall quality score for all 194 hospitals with complete data (μ=81.26). The mean score for process of care quality (μ=86.03) was also below the overall mean process of care quality score (μ=89.00). Mean patient satisfaction (μ=72.59) was slightly higher for this sample of hospitals than the overall mean patient satisfaction score (μ=71.57).

Table 4.2

Descriptive Statistics for Quality Variables

Variable	Mean	SD	Min	Max
Overall Quality	80.44	3.76	72.84	86.64
Patient Satisfaction	72.59	7.56	62.70	84.60
Process of Care	86.03	10.47	64.33	97.58

Recordings were transcribed from each interview to extract data for the complexity variables shown in Table 4.3. Definitions for each of the complexity variables can be found in the methods section. Overall complexity scores are also given according to hospital characteristics in Table 4.4.

Table 4.3

Descriptive Statistics for Complexity Variables

Variable	Mean	SD
Individual Complexity Scores		
PI: Provider Interaction	2.29	0.23
SI: Staff Interaction	0.40	0.17
RT: Room Transfer	0.71	0.20
DT: Department Transfer	0.24	0.09
IN: Information Provision	1.42	0.19
PS: Patient Steps	3.11	0.38
PE: Personnel Involved	2.84	0.34
PT: Personnel Travel	1.73	0.33
IT: Information Transfer	2.49	0.59
CD: Care Documentation	2.20	0.59
DP: Decision Points	0.82	0.12
TS: Total Steps	7.78	0.73
Overall Complexity Scores by Process		
COM1: Registration Process Complexity	0.61	0.14
COM2: Laboratory Process Complexity	0.61	0.07
COM3: Medication Administration Process Complexity	0.65	0.07
COM4: Radiology Process Complexity	0.82	0.05
COM5: Discharge Process Complexity	0.50	0.13
Overall Complexity Scores		
PAT: Overall Patient-focused Complexity	0.56	0.06
PRO: Overall Provider-focused Complexity	0.72	0.09
COM: Overall Complexity	0.64	0.05

Table 4.4

Descriptive Statistics by Hospital Characteristics

Size Quartile	**N**	**Complexity**	**Mean**	**SD**
1	2	PAT	0.52	0.04
		PRO	0.74	0.13
		COM	0.63	0.09
2	3	PAT	0.60	0.04
		PRO	0.68	0.13
		COM	0.64	0.05
3	3	PAT	0.52	0.05
		PRO	0.72	0.07
		COM	0.62	0.05
4	1	PAT	0.63	-
		PRO	0.74	-
		COM	0.69	-
Quality Cluster	**N**	**Complexity**	**Mean**	**SD**
A	4	PAT	0.57	0.08
		PRO	0.65	0.09
		COM	0.61	0.05
B	2	PAT	0.53	0.08
		PRO	0.73	0.04
		COM	0.63	0.06
C	3	PAT	0.56	0.01
		PRO	0.80	0.04
		COM	0.68	0.02
State	**N**	**Complexity**	**Mean**	**SD**
AL	3	PAT	0.59	0.04
		PRO	0.77	0.03
		COM	0.68	0.01
LA	2	PAT	0.48	0.01
		PRO	0.67	0.04
		COM	0.58	0.01
MS	4	PAT	0.57	0.05
		PRO	0.70	0.12
		COM	0.64	0.05

In general, complexity variables showed less variation than that anticipated prior to collecting data. Low variation in complexity variables suggests much similarity among the operations of these nine hospitals for the five processes measured in this study.

Hypotheses

Pearson correlation coefficients were calculated using SAS v9.2 to quantify the relationship between patient-focused complexity (PAT) and patient satisfaction, provider-focused complexity (PRO) and process of care quality, and overall complexity (COM) and overall quality. The inverse relationships hypothesized for complexity and quality measures were supported in this analysis. However, negative correlations were significant ($p < 0.10$) only for the relationship between overall complexity and overall quality. Table 4.5 shows Pearson correlation coefficients (r) and P-values for the hypothesized relationships.

Table 4.5

Correlations between Complexity and Quality Variables

Complexity Variable	Quality Variable	r	P-value
Overall complexity	Overall quality	-0.62	0.08
Patient-focused complexity	Patient satisfaction	-0.23	0.54
Provider-focused complexity	Process of care quality	-0.38	0.31

The strongest negative correlation exists between overall complexity and overall quality, suggesting that hospitals with less complex processes have higher quality outcomes. Though overall complexity was a product of patient-focused and provider-focused complexity, neither of these complexity measures alone was significantly correlated with overall quality or individual components of overall quality (i.e. patient satisfaction and process of care quality). This suggests that both patient-focused and provider-focused measures are necessary in obtaining an accurate picture of complexity's effect on quality outcomes. Given that these variables do have an inverse relationship with overall quality, and overall complexity is an average of patient-focused and provider-focused complexity scores, high values for either of these measures may negatively impact overall quality.

Predictive Models

In order to further investigate the hypothesized relationship between process complexity and quality, regression analysis was used to develop predictive models of hospital quality. Three versions of hospital complexity scores were considered as predictors of overall quality: individual complexity variables, overall complexity scores by process, and overall hospital complexity.

Individual Complexity Variables

One goal of regression analysis was to determine relative weights of importance for the twelve complexity variables in explaining variance in overall quality. In order to investigate which variables were most effective in predicting overall quality, all twelve complexity variables (IT, SI, RT, DT, IN, PS, PE, PT, IT, CD, DP, TS) were included as predictors in a model of overall quality. The resulting model was statistically biased due to the effects of multicollinearity.

Multicollinearity occurs as a result of strong correlation between one or more predictors in a regression model. The result of multicollinearity is a model in which the regression coefficients of predictors have inflated variance (Kutner, 2004). Correlation proved to be present among many of individual complexity variables, as shown in Table 4.6. Values in bold represent correlation >.75.

Table 4.6

Correlation Coefficients of Complexity Variables

Variable	PI	SI	RT	DT	IN	PS	PE	PT	IT	CD	DP	TS
PI	1.00											
SI	-0.13	1.00										
RT	0.19	**0.85****	1.00									
DT	-0.22	0.65*	0.25	1.00								
IN	0.30	0.31	0.32	0.24	1.00							
PS	**0.75****	0.38	0.74**	-0.17	0.32	1.00						
PE	0.52	0.59*	0.50	0.59	0.30	0.54	1.00					
PT	**0.82****	-0.26	0.12	-0.40	0.27	0.67**	0.25	1.00				
IT	0.64*	-0.19	0.16	-0.56	-0.20	0.56	0.17	0.36	1.00			
CD	0.60*	-0.24	0.08	-0.57	0.00	0.47	0.07	0.33	**0.91****	1.00		
DP	0.65*	-0.24	-0.11	-0.10	-0.25	0.27	0.46	0.29	0.74	0.56	1.00	
TS	0.62*	0.08	0.46	-0.45	-0.03	0.74**	0.20	0.36	**0.88****	**0.88****	0.46	1.00

*denotes significant correlation at α=0.10
**denotes significant correlation at α=0.05

Due to the effects of multicollinearity, the model including all complexity variables was not accurate in predicting overall quality. In order to limit the number of predictors in the model and reduce the effects of multicollinearity, predictors that were highly correlated (r > 0.75) with other predictors were removed from the model. The reduced the model including five complexity variables (PI, SI, DT, IN, PE) achieved the desired effect of reducing multicollinearity. However, predictors remaining in the model had large standard errors, suggesting that multicollinearity was still present, and the overall model was not significant. Thus, a different approach was sought in quantifying the relative importance of individual complexity variables in predicting overall hospital quality.

In modeling each of the complexity variables independently in simple linear regression models of overall quality, variables which significantly impact overall quality were identified. The variable found to most accurately explain the variance in overall quality was PS, the number of process steps involving the patient. PS was found to be a significant predictor of overall quality, F(1,7)=9.06, p=.02. The linear model of overall quality based on PS explains approximately fifty percent of variation in overall quality (Adj. R^2= .50). This model is given in equation 4-1. The practical range of PS is between 2 and 8. Based on this model, a hospital able reduce PS by one step could achieve an increase in their overall quality score of 7.5 points.

$$\textit{Overall Quality} = 103.83-7.5\ (\textit{PS}) \qquad (4\text{-}1)$$

Total process steps, TS, was also found to be a significant predictor of overall quality (F(1,7)= 5.10, p=.06), but the data for this model did not uphold the assumptions of linear regression. Specifically, results of the Shapiro-Wilk test for normality suggested that model data was non-normal. Figure 4-1 shows a scatterplot of values for TS and overall quality. Multiple observations resulted in identical values for TS; this appears to have affected the test for normality in this small sample size.

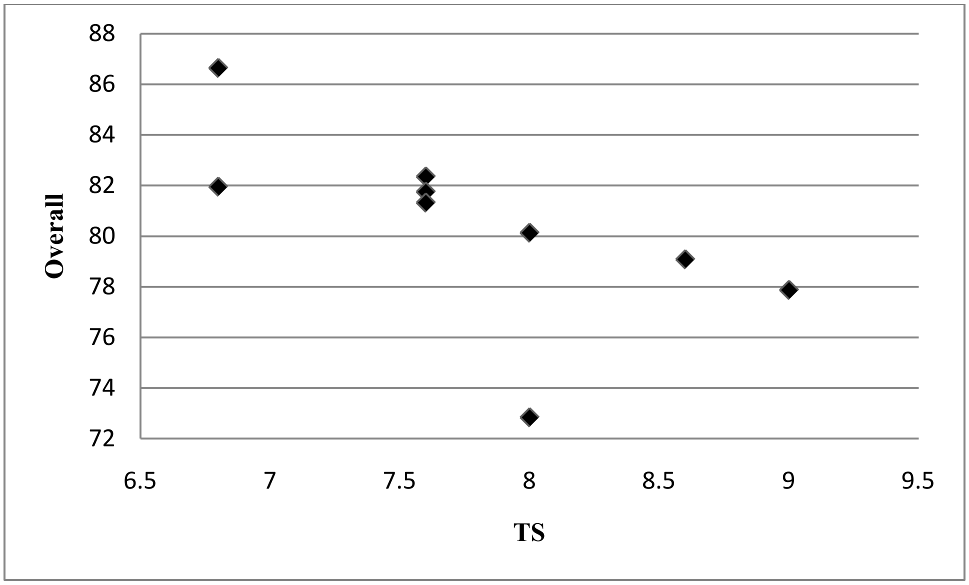

Figure 4.1 Scatter-plot of total steps and overall quality

Other complexity variables explained little to no variation in overall quality. For instance, the number of process steps requiring patients to provide information (IN), contributed to less than one percent of variation in overall complexity (Adj. $R^2 < .00$). Similarly, the number of process decision points, DP, was found to be a poor predictor of overall quality. This model explained no variation in overall quality (Adj. $R^2 = -.13$).

Overall Complexity by Process

The overall complexity scores of each five processes were also considered as predictors of overall quality. The goal of this analysis was to identify which processes may have a greater impact on quality outcomes than others. Linear regression showed that overall complexity of the registration process (COM1) was a significant predictor of overall quality, $F(1,7)=6.86$, $p=0.03$. Registration process complexity explains over forty percent of variation in overall quality (Adj. $R^2=0.42$). Equation 4-2 shows overall complexity as a linear function of registration process complexity. Adding the overall complexity scores of other processes (COM2, COM3, COM4, COM5) as predictors of overall quality only weakened the model. The practical range of COM1 is between 0.4 and 0.78. Based on this model, a hospital able reduce COM1 by 0.1 units could obtain an increase in their overall quality score of 1.89 points.

$$\textit{Overall Quality} = 91.95 - 18.98\,(\textit{COM1}) \qquad (4\text{-}2)$$

Overall Complexity

Regression analysis was also used to further investigate the relationship confirmed by negative correlation between overall process complexity (COM) and overall quality (see Table 4.4). Establishing COM as a significant predictor of overall quality could suggest that equations used to measure process complexity are effective for the purposes of predicting impact on overall quality. A linear regression model, given in equation 4-3, showed that COM explained nearly thirty percent of variation in overall quality (Adj. $R^2 = .29$). The high standard error (21.46) of process complexity in this model may be a cause for concern.

$$\textit{Overall Quality} = 108.75 - 44.47(\textit{COM}) \qquad (4\text{-}3)$$

Figure 4.2 is a scatter-plot of process complexity and overall quality scores. Based on observation, the poor fit obtained by the linear model in equation 4-3 could be caused by an outlying quality value.

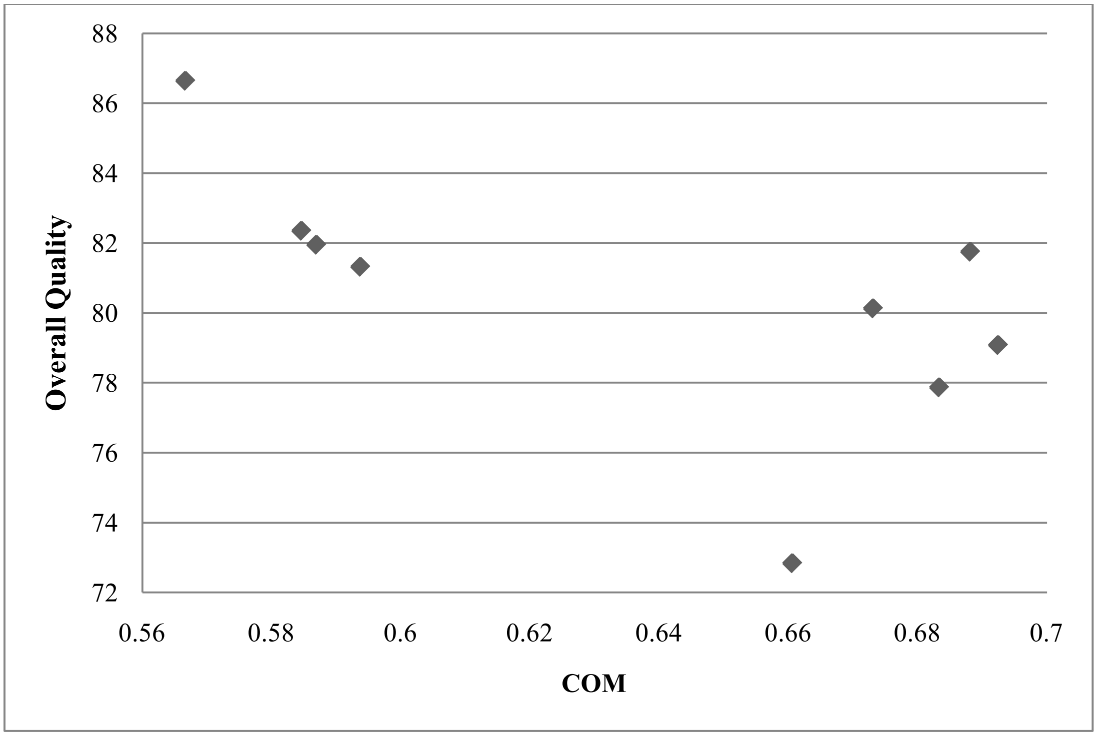

Figure 4.2 Scatter-plot of process complexity and overall quality

The linear relationship between process complexity and overall quality became much stronger when the hospital with the lowest quality score was removed ($F(1,7)=8.00$, $p= .03$). Equation 4-4 depicts overall quality as a linear function of process complexity. This model explains approximately fifty percent of variation in overall quality (Adj. $R^2=.50$). Additionally, the standard error of the complexity term was reduced from 21.46 to 12.78. The practical range of COM is between 0.56 and 0.66. Based on this model, a hospital able reduce COM by 0.1 units could achieve an increase in their overall quality score of 3.61 points.

$$Overall\ Quality = 104.28 - 36.13(COM) \quad (4\text{-}4)$$

Other Predictive Models

Additional regression analyses were consistent with the correlations found between patient-focused complexity and patient satisfaction, and provider-focused complexity and process of care quality (see Table 4.5). Negative regression coefficients of predictors in these models suggest inverse relationships between complexity and quality. However, neither patient-focused nor provider-focused complexity had a significant impact on either component of overall quality (patient satisfaction or process of care quality). Inverse relationships were also supported by models of patient-focused and provider-focused complexity as predictors of overall quality, yet neither complexity component alone explained a significant amount of variation in overall quality.

Summary

Table 4.7 provides a summary of significant predictors of overall quality. All models were tested to ensure that regression assumptions were met.

Table 4.7

Significant Predictors of Overall Hospital Quality

IV	DV	F (1,7)	P-value	Adj. R^2	Shapiro-Wilk (P-value)
PS	Overall quality	9.06	0.02	0.50	0.24
COM1	Overall quality	6.86	0.03	0.42	0.36
COM*	Overall quality	8.00	0.03	0.50	0.14

*denotes outlier removed from data

CHAPTER V

DISCUSSION

Variance in ED Processes

In general, hospitals demonstrated many similarities in the processes of registration, laboratory testing, medication administration, radiology, and discharge. Given the large amount of process similarity among hospitals, it is important to note the individual complexity variables that had highest standard deviation: the total number of process steps (TS), information transfers (IT), and steps of care documentation (CD). Variables with high standard deviations are of interest because they point to differences in ED operations that could represent areas for improvement. Regardless of a potential impact on quality outcomes, it is interesting from an efficiency standpoint to note where some hospitals are able to eliminate steps, information transfers and care documentations in core processes.

Strong correlation among TS, IT, and CD (see Table 4.6) suggests that hospitals may be able to simultaneously lower scores for all three of these variables by concentrating on any one of these variables. Intuitively, as steps involving information transfer or care documentation increase, the total number of process steps, TS, must also increase. The correlation between IT and CD is less intuitive but is likely due to the fact that hospitals that utilize CPOE eliminate steps involving both of these activities. Specifically, when a physician enters an order via CPOE, orders are electronically transferred to the lab and automatically posted to the patient's electronic chart, thereby eliminating steps of documenting the order on a paper chart, notifying the primary nurse of a standing order, and calling the respective department responsible for completing the order. Thus, hospitals whose processes involve a large number of care documentation steps are also likely to have a high number of information transfers.

While high variance complexity variables may identify leverage points for improving ED operations, low complexity variables may identify areas that are difficult to improve upon. For instance, the number of department transfers, DT, had lowest deviation among hospitals. While the mean DT across processes was less than one, the low standard deviation in this variable suggests that one DT may be unavoidable. One variation that was anticipated in the number of department transitions was the use of portable imaging equipment or an imaging room located within the ED versus performing X-rays in the radiology department. All of the hospitals in this sample reported that X-rays were performed in the radiology department, requiring patients to be transported there. While it may be possible to lower the DT score through an imaging area dedicated to the ED, it is likely that the cost and resources required of this change are not feasible.

Results also showed a range of variance in overall complexity scores based on process. Variation was highest for the processes of registration (COM1) and discharge (COM5). Less variation was present in laboratory (COM2), medication administration (COM3), and radiology (COM4) processes. It is possible that this difference could be due to the fact that registration and discharge processes are more heavily focused on administrative rather than clinical tasks. Unlike administrative tasks, clinical tasks are more strictly regulated by standard operating procedures or best practices to protect patient safety. For example, most hospitals reported using the "5 Rights" method of medication administration to verify patient ID against medication orders prior to administering.

Implications of Predictive Models of Quality

Results showed a negative impact on overall hospital quality from high process complexity scores. Specifically, predictive models of quality suggest that the individual complexity variable for patient steps in a process, PS, and the overall complexity score of the registration process, COM1, are significant predictors of overall quality. Therefore, it is important to examine how high quality hospitals in the sample achieved lower scores for these complexity variables.

Reduce Process Steps

The complexity variable that showed a significant impact on overall quality was PS, the number of process steps involving patients. This finding suggests that hospitals should attempt to reduce the number of steps involving patients in core processes in order to positively impact quality outcomes. Reducing the number of process steps can be achieved in a number of ways. As previously mentioned, one method of streamlining core processes is the use of CPOE for tasks involving physician orders (e.g. laboratory, medication, radiology). However, CPOE is likely more effective in reducing provider-focused complexity, as process steps eliminated by CPOE do not involve patients. Reducing the number of patient steps may be more easily achieved by focusing on the non-clinical processes of registration and discharge. Variations in registration and discharge processes were evident from the high standard deviations in hospitals' complexity scores for these processes. Some hospitals required extra steps of patients in the discharge process by collecting a "co-pay" from patients before they exit the ED. Other hospitals do not require this collection procedure and allow patients to exit immediately after receiving discharge instructions. Additional steps involving patients that some hospitals were able to eliminate will be presented in the following section dedicated to the registration process.

Reduce Registration Process Complexity

In addition to having the highest variance among the five processes, registration process complexity was shown to be a significant predictor of overall hospital quality. This suggests that hospitals should concentrate on reducing complexity in the registration process in order to improve overall quality. In examining how some hospitals achieved lower COM1 scores than others, one of the noticeable differences among hospitals was whether patients were seen by a physician prior to completing the full registration process. For billing purposes, many hospitals require that a physician or nurse practitioner declares a patient as "emergent" rather than "non-emergent" before a registration clerk registers him or her as an ED patient. In effect, this method requires more steps to take place between a patient's arrival and completion of the registration process. Other hospitals in this sample reported that the full registration process was initiated immediately after the triage nurse has assigned an acuity level to the patient, thus eliminating some of the activity involved in the prior method. Given that registration process complexity was found to be a significant predictor of overall hospital quality, the abbreviated method of patient registration is preferable.

Additional variations in the registration process among hospitals present other possibilities for reducing complexity. For example, some hospitals were able to eliminate the step in which a registration clerk notifies the triage nurse of a patient's arrival by implementing cameras that allow nurses to monitor the patient arrival area from their workstations or by stationing the triage nurse near the registration area.

Summary

Findings were consistent with the theoretical relationship between complexity and quality acknowledged in the literature. A significant negative correlation was found between process complexity and overall quality, suggesting that hospitals with highly complex processes may experience lower quality outcomes when patient satisfaction, process of care standards, and mortality and readmission rates are considered as factors in overall quality. Further evidence of a quantifiable relationship between process complexity and overall quality was demonstrated in predictive models of overall quality based on complexity variables. Regression analysis gave insight into which variables considered in measuring process complexity are most effective in predicting quality. Specifically, the average number of patient steps in core process was found to be a strong predictor of overall quality. Results also gave insight into which core processes are of interest in attempts to reduce potential negative impacts of complexity on quality. Registration process complexity was found to be a significant predictor of overall quality, suggesting that the registration process may be a valuable area of focus in improving ED operations.

CHAPTER VI

CONCLUSION

The purpose of this study was to determine whether a quantifiable relationship exists between process complexity and quality of care in hospital emergency departments. Equations for patient-focused, provider-focused, and overall complexity of healthcare processes were developed. Nine emergency department nurse managers from hospitals in Mississippi, Alabama, and Louisiana were interviewed regarding processes of registration, laboratory testing, medication administration, radiology, and discharge. Interview data was coded according to variables in the proposed complexity equations for each of these processes. Hospital quality was measured using scores for patient satisfaction, process of care, and outcome of care quality standards provided by a public database.

Results showed much similarity in the way processes are performed by hospitals in this sample. However, notable differences were evident in complexity scores among hospitals, particularly in the processes of registration and discharge. The number of patient steps in a process was found to be a significant predictor of overall quality. Additionally, the overall complexity of the registration process was found to be a significant predictor of quality. Strong negative correlation between process complexity and overall quality suggests that hospitals with less complex processes have higher quality outcomes. A predictive model of this relationship (equation 4-4) provided further evidence of a quantifiable relationship between process complexity and overall quality.

This study has a number of limitations which should be considered along with the results presented. First, a small sample of hospitals was included. The first priority of future research will involve increasing the sample size of hospitals. The current sample of hospitals ranged in size and quality characteristics, but most hospitals were in the mid-range of size and quality scores for hospitals in the three-state region. An enlarged sample should achieve a better balance of these criteria.

Further work may also include revising equations for patient-focused and provider focused complexity. Given that the model of overall complexity and overall quality was significant for the limited sample of hospitals (see Table 4.7), initial results suggest that COM may be an effective complexity measure. However, strong correlation was found between many complexity variables, suggesting that some variables may be redundant or unnecessary in measuring process complexity. The small current sample limited possibilities for validating the proposed complexity equations. Further work should include validating the proposed complexity measures by repeating the study on multiple samples.

In conclusion, this study provides empirical evidence of the theoretical relationship that many researchers have proposed between complexity and quality in healthcare systems. Results suggest that efforts to streamline healthcare processes, reducing the complexity experienced by patients and providers, may be an effective means of improving quality outcomes.

REFERENCES

Agency for Healthcare Research and Quality. (2009). Retrieved February 1, 2010, from World Wide Web: http://statesnapshots.ahrq.gov/snaps08/meter_metrics.jsp?menuId=4&state=AL&level=2&region=0&compGroup=N

Anderson, R., Crabtree, B.F., Steele, D.J., & McDaniel, R.R.. (2005). Case study research: the view from complexity science. *Qualitative Health Research*, 15, 669-685.

Anyanwu, K., Sheth, A. , Cardoso, J. , Miller, J., & Kochut, K. (2003). Healthcare process development and integration. *Journal of Research and Practice in Information Technology*, 35, 83-98.

Ball, M.J. & Bierstock, S. (2007). Clinician use of enabling technology. *Journal of Healthcare Information Management*, 21, 68-71.

Barr, D.A. (1995). The effects of organizational structure on primary care outcomes under managed care. *Annals of Internal Medicine*, 122, 353-359

Bullock, S. & Cliff, D. (2004). Complexity and Emergent Behaviour in ICT Systems. Retrieved February 10, 2010 from http://eprints.ecs.soton.ac.uk/11478/1/HPL-2004-187.pdf

Buse, R.P. & Weimer, W. R. (2008). A metric for software readability. *Proceedings of the. International Symposium on Software Testing and Analysis*. 121–130.

Calinescu, A., Efstathiou, J, Sivadasan, S, Schirn, J., Huaccho Huatuco, L. (2000). Complexity in manufacturing: an information theoretic approach. Proceedings of the International Conference on Complex Systems and Complexity in Manufacturing, 30-44.

Cardoso, J. (2006). Approaches to Compute Workflow Complexity. *Proceedings Of Dagstuhl Seminar: The Role of Business Processes in Service Oriented Architectures*

Committee on the Future of Emergency Care in the United States Health System. (2007). *Hospital-based emergency care: at the breaking point*. Washington, DC: National Academies Press.

Cuellar, A.E. & Gertler, P.J. (2005). How the expansion of hospital systems has affected consumers. *Health Affairs,* 2, 213-219.

Dietrich, Damon. (2010). Electronic Patient Tracking Systems: A Healthy IT Investment for Emergency Departments. Retrieved September 24, 2010 from World Wide Web: http://www.medscape.com/viewarticle/717534

Donabedian A. (1988). The quality of care: how can it be assessed? Journal of the American Medical Associatio, 260,1743-1748.

Fraass, B., Lash, K. , Matrone, G. , Volkman, S.K. , McShan, D.L , & Kessler, M.L. (1998). The impact of treatment complexity and computer control delivery technology on treatment delivery errors. *International Journal of Radiation Oncology Biology Physics*, 42, 651-659.

France, D.J, & Levin, S. (2006). System complexity as a measure of safe capacity for the emergency department. *Academic Emergency Medicine,* 13,1212-1219.

Galloway, T.J., & Drury, C.G. (1986). Task Complexity in visual inspection. *Human Factors*, 28, 595-606.

Hibbard, J. (2003). Engaging Health Care Consumers to Improve the Quality of Care. *Medical Care,* 41, I61-I70.

Hinckley, C.M. (2003). Make no mistake—errors can be controlled. *Quality and Safety in Health Care,* 12, 359-365.

Hinckley, C.M., & Barkman, P. (1995). The role of variation, mistakes, and complexity in producing nonconformities. *Journal of Quality Technoogy,* 27,242-249.

Horgan, J. (1995). From Complexity to Perplexity. *Scientific American,* June, 104-109.

Hospital Consumer Assessment of Healthcare Providers and Systems. (2010). Retrieved April 19, 2010 from World Wide Web: http://www.hcahpsonline.org/files/HCAHPS%20Fact%20Sheet,%20revised1,%203-31- 09.pdf

Institute for Healthcare Improvement. (2010). Overview of the 5 million lives campaign. Retrieved April 19, 2010 from World Wide Web: http://www.ihi.org/IHI/Programs/Campaign/Campaign.htm?TabId=1

Kennedy, R., & Coulter, X. (1975). Research note: the interactions among stress, vigilance, and task complexity. *Human Factors*, 17(1), 106-109.

Kohn, L., Corrigan, J. & Donaldson, M. (2000). *To Err Is Human: Building a Safer Health System*. Washington: National Academy Press.

Kuperman, G.J. & Gibson, R.F. (2003) Computer Physician Order Entry: Benefits, Costs, and Issues. *Annals of Internal Medicine*, 139, 31-39.

Kutner, M., Nachtsheim, C., and Neter, J. (2004). *Applied Linear Regression Models* (4th ed.). New York, NY: McGraw Hill/Irwin.

Leape L. (1994). Error in Medicine. *Journal of the American Medical Association.* 272, 1851-1857.

Meadows, D. (2008). *Thinking in Systems*: *A primer*. White River Junction, VT: Chelsea Green Publishing.

Moses, J., & Sussman, J.M.. 2003. Collected Views on Complexity in Systems. *Proceedings of the Engineering Systems Division (ESD) Internal Symposium*. Cambridge, MA: MIT Press, 453-478.

Nolan, T. (2000). System changes to improve patient safety. *British Medical Journal,* 320,771-773.

Payne, J. (1976). Task complexity and contingent processing in decision-making: An information search and protocol analysis. *Organizational Behavior and Human Performance*, 16, 366-387.

Perrow, C. (1999). *Normal Accidents: Living with High-Risk Technologies*. Princeton, NJ: Princeton Press.

Pitts, S.R., Niska R.W., Xu, J., & Burt, C.W. (2008). National Hospital Ambulatory Medical Care Survey: 2006 Emergency Department Summary. National Health Statistics Reports; No. 7. Hyattsville, MD: National Center for Health Statistics.

Plsek, P.E. & Greenhalgh, T. (2001). The challenge of complexity in health care. *British Medical Journal,* 323, 626-628.

Roberts, J, Coale, J. , & Redman, R. (1987). A History of the Joint Commission on Accreditation of Hospitals. *Journal of the American Medical Association,* 258, 36-40.

Rouse, W.B. (2008). Healthcare as a complex adaptive system. *The Bridge,* 38, 17-25.

Solberg, LI, Asplin, R., Weinick, R.M., & Magid, D.J. (2003). Emergency department crowding: consensus development of potential measures. *Annals of Emergency Med*icine, 14, 247-249.

Strawderman, L., Salehi, A., & Ruff, L. (2009, July). The importance of communication for patient satisfaction. *Society for Health Systems Newsletter*. Retreieved from World Wide Web: http://www.iienet2.org/SHS/Details.aspx?id=15572

Strong, M. (1999). Simplifying the approach: what can we do? *Neurology* 53, S31-34.

U.S. Department of Health and Human Services. (2010). Information for Professionals on Data Collection. Retrieved on April 19, 2010 from World Wide Web: http://www.hospitalcompare.hhs.gov/Hospital/Static/InformationForProfessionals tabset. asp?activeTab=1&language=English&version=default

Weingart, S.N., Wilson, R.W. Gibberd, R.W., & Harrison, B. (2000). Epidemiology of medical error. *British Medical Journal,* 320,774-777.

West, E. (2001). Management matters: the link between hospital organisation and quality of patient care. *Quality in Health Care*, 10,40-48.

Woods, D. (2000). Behind human error: human factors research to improve patient safety. *National summit on medical errors and patient safety research*, *Quality Interagency Coordination Task Force and Agency for Healthcare Research and Quality.*

Woods, D. & Cook, R.I. (2001). From Counting Failures to Anticipating Risk. In: Zipperer, L., Cushman, S., eds. *Lessons in Patient Safety: A Primer*. Chicago, IL: National Patient Safety Foundation. 1-10.

Woods, D., & Cook, R.I. (2002). Nine steps to move forward from error. *Cognition Technology & Work,*4,137-144.

APPENDIX A

QUALITY MEASURES

Table A.1

Process of Care Quality Measures

Heart Attack Measures		
Measure Name	**Measure Description**	**Brief Explanation**
AMI-1	Percent of Heart Attack Patients Given Aspirin at Arrival	Aspirin can help keep blood clots from forming and dissolve blood clots that can cause heart attacks.
AMI-2**	Percent of Heart Attack Patients Given Aspirin at Discharge	Taking aspirin may help prevent further heart attacks.
AMI-3**	Percent of Heart Attack Patients Given ACE Inhibitor or ARB for Left Ventricular Systolic Dysfunction (LVSD)	ACE (angiotensin converting enzyme) inhibitors and ARBs (angiotensin receptor blockers) are medicines used to treat heart attacks, heart failure, or a decreased function of the heart.
AMI-4**	Percent of Heart Attack Patients Given Smoking Cessation Advice/Counseling	Smoking is linked to heart attacks. Quitting may help prevent another heart attack.
AMI-5**	Percent of Heart Attack Patients Given Beta Blocker at Discharge	Beta blockers are a type of medicine used to lower blood pressure, treat chest pain (angina) and heart failure, and to help prevent a heart attack.
AMI-7A**	Percent of Heart Attack Patients Given Fibrinolytic Medication Within 30 Minutes Of Arrival	Blood clots can cause heart attacks. Doctors may give this medicine, or perform a procedure to open the blockage, and in some cases, may do both.
AMI-8A**	Percent of Heart Attack Patients Given PCI Within 90 Minutes Of Arrival	The procedures called Percutaneous Coronary Interventions (PCI) are among those that are the most effective for opening blocked blood vessels that cause heart attacks. Doctors may perform PCI, or give medicine to open the blockage, and in some cases, may do both.
Heart Failure Measures		
Measure Name	**Measure Description**	**Brief Explanation**
HF-1	Percent of Heart Failure Patients Given Discharge Instructions	The staff at the hospital should provide you with information to help you manage your heart failure symptoms when you are discharged.
HF-2	Percent of Heart Failure Patients Given an Evaluation of Left Ventricular Systolic (LVS) Function	An evaluation of the LVS function checks how the left chamber of the heart is pumping.
HF-3	Percent of Heart Failure Patients Given ACE Inhibitor or ARB for Left Ventricular Systolic Dysfunction (LVSD)	ACE (angiotensin converting enzyme) inhibitors and ARBs (angiotensin receptor blockers) are medicines used to treat heart attacks, heart failure, or a decreased function of the heart.
HF-4	Percent of Heart Failure Patients Given Smoking Cessation Advice/Counseling	Smoking is linked to heart failure. Quitting may help improve your condition.
Pneumonia Measures		
Measure Name	**Measure Description**	**Brief Explanation**
PN-1	Percent of Pneumonia Patients Given Oxygenation Assessment	Hypoxemia is a known risk factor for poor outcomes in patients with pneumonia. Supplemental oxygen has been shown to decrease mortality in patients with pneumonia.
PN-2	Percent of Pneumonia Patients Assessed and Given Pneumococcal Vaccination	A pneumonia (pneumococcal) shot can help prevent pneumonia in the future, even for patients who have been hospitalized for pneumonia.

Table A.1 (continued)

PN-3B	Percent of Pneumonia Patients Whose Initial Emergency Room Blood Culture Was Performed Prior To The Administration Of The First Hospital Dose Of Antibiotics	A blood culture tells what kind of medicine will work best to treat your pneumonia.
PN-4	Percent of Pneumonia Patients Given Smoking Cessation Advice/Counseling	Smoking is linked to pneumonia. Quitting may help prevent you from getting pneumonia again.
PN-5C	Percent of Pneumonia Patients Given Initial Antibiotic(s) within 6 Hours After Arrival	Timely use of antibiotics can improve the treatment of pneumonia caused by bacteria.
PN-6	Percent of Pneumonia Patients Given the Most Appropriate Initial Antibiotic(s)	Antibiotics are medicines that treat infection, and each one is different. Hospitals should choose the antibiotics that best treat the infection type for each pneumonia patient.
PN-7	Percent of Pneumonia Patients Assessed and Given Influenza Vaccination	An influenza shot can help prevent influenza in the future, even for patients who have been hospitalized for pneumonia.
Surgical Care Improvement Project (SCIP) Measures		
Measure Name	**Measure Description**	**Brief Explanation**
SCIP-INF-1**	Percent of patients who got treatment at the right time (within 24 hours before or after their surgery) to help prevent blood clots after certain types of surgery	This measure tells how often patients having certain types of surgery received treatment to prevent blood clots in the period from 24 hours before surgery to 24 hours after surgery.
SCIP-VTE-1**	Percent of surgery patients whose doctors ordered treatments to prevent blood clots after certain types of surgeries	Certain types of surgery can increase patients' risk of having blood clots after surgery. For these types of surgery, this measure tells how often treatment to help prevent blood clots was ordered by the doctor.
SCIP-INF-2**	Percent of surgery patients who were given the right kind of antibiotic to help prevent infection	Some antibiotics work better than others to prevent wound infections for certain types of surgery. This measure shows how often hospital staff make sure patients get the right kind of preventive antibiotic medication for their surgery.
SCIP-INF-3**	Percent of surgery patients whose preventive antibiotics were stopped at the right time (within 24 hours after surgery)	Taking preventive antibiotics for more than 24 hours after routine surgery is usually not necessary. This measure shows how often hospitals stopped giving antibiotics to surgery patients when they were no longer needed to prevent surgical infection.
SCIP-INF-4 **	Percent of all heart surgery patients whose blood sugar (blood glucose) is kept under good control in the days right after surgery	All heart surgery patients get their blood sugar checked after surgery. Any patient who has high blood sugar after heart surgery has a greater chance of getting an infection. This measure tells how often the blood sugar of heart surgery patients was kept under good control in the days right after their surgery.
SCIP-INF-6**	Percent of surgery patients needing hair removed from the surgical area before surgery, who had hair removed using a safer method (electric clippers or hair removal cream – not a razor)	For those patients who needed to have hair removed to prepare for surgery, this measure tells how often one of the safer methods was used (electric clippers or hair removal cream).
SCIP-INF-1**	Percent of surgery patients who were given an antibiotic at the right time (within one hour before surgery) to help prevent infection	Getting an antibiotic within one hour before surgery reduces the risk of wound infections. This measure shows how often hospital staff make sure surgery patients get antibiotics at the right time.

Table A.1 (continued)

SCIP-VTE-2**	Percent of surgery patients who were taking heart drugs called beta blockers before coming to the hospital, who were kept on the beta blockers during the period just before and after their surgery	Many people who have heart problems or are at risk for heart problems take drugs called beta blockers to reduce the risk of future heart problems. This measure shows whether surgery patients who were already taking beta blockers before coming to the hospital were given beta blockers during the time period just before and after their surgery.
CAC-1**	Percent of Children Who Received Reliever Medication While Hospitalized for Asthma	National guidelines recommend using reliever medication in the severe phase and gradually cutting down the dosage of medications to provide control of asthma symptoms. Relievers are medications that relax the bands of muscle surrounding the airways and are used to quickly make breathing easier.
CAC-2**	Percent of Children Who Received Systemic Corticosteroid Medication (oral and IV Medication That Reduces Inflammation and Controls Symptoms) While Hospitalized for Asthma	National guidelines recommend using systemic corticosteroid medication (oral and IV medication that reduces inflammation and controls symptoms) in the severe phase and gradually cutting down the dosage of medications to provide control of the asthma symptoms. Systemic corticosteroids are a type of medication that work in the body as a whole. Systemic corticosteroids help control allergic reactions and reduce inflammation.
CAC-3**	Percent of Children and their Caregivers Who Received a Home Management Plan of Care Document While Hospitalized for Asthma	The Home Management Plan of Care document includes arrangements for follow-up care. The plan of care should clearly tell the child and their caregiver how to manage the child's asthma symptoms.

**denotes measure removed due to missing data

Note. Adapted from "Information for Professionals on Data Collection." Retrieved on April 19, 2010 from World Wide Web: http://www.hospitalcompare.hhs.gov/staticpages/for-professionals/poc/Technical-Appendix.aspx#POC3

Table A.2

Outcome of Care Quality Measures

Mortality Measure Name	Brief Explanation
Hospital 30-Day Death (Mortality) Rates for Heart Attack**	Risk adjusted percentage of patients hospitalized with a principal diagnosis of heart attack that died from any cause within 30 days after the admission date, regardless of whether patient dies while still in the hospital or after discharge
Hospital 30-Day Death (Mortality) Rates for Heart Failure	Risk adjusted percentage of patients hospitalized with a principal diagnosis of heart failure that died from any cause within 30 days after the admission date, regardless of whether patient dies while still in the hospital or after discharge
Hospital 30-Day Death (Mortality) Rates for Pneumonia	Risk adjusted percentage of patients hospitalized with a principal diagnosis pneumonia that died from any cause within 30 days after the admission date, regardless of whether patient dies while still in the hospital or after discharge
Readmission Measure Name	**Brief Explanation**
Hospital 30-Day Readmission Rates for Heart Attack**	Percentage of patients readmitted within 30 days of discharge from a previous hospital stay for heart attack. Patients may have been readmitted back to the same hospital or to a different hospital or acute care facility. They may have been readmitted for the same condition as their recent hospital stay, or for a different reason.
Hospital 30-Day Readmission Rates for Heart Failure	Percentage of patients readmitted within 30 days of discharge from a previous hospital stay for heart failure. Patients may have been readmitted back to the same hospital or to a different hospital or acute care facility. They may have been readmitted for the same condition as their recent hospital stay, or for a different reason.
Hospital 30-Day Readmission Rates for Pneumonia	Percentage of patients readmitted within 30 days of discharge from a previous hospital stay for pneumonia. Patients may have been readmitted back to the same hospital or to a different hospital or acute care facility. They may have been readmitted for the same condition as their recent hospital stay, or for a different reason.

**denotes measure removed due to missing data

Note. Adapted from "Information for Professionals on Data Collection." Retrieved on April 19, 2010 from World Wide Web: http://www.hospitalcompare.hhs.gov/staticpages/for-professionals/ooc/calculation-of-30-day-risk.aspx

Table A.3

Patient Satisfaction Measures

Measure Name	Measure Description	Brief Explanation
H_COMP_1_A_P	How often did nurses communicate well with patients?	Percent of patients who reported that their nurses "Always" communicated well.
H_COMP_2_A_P	How often did doctors communicate well with patients?	Percent of patients who reported that their doctors "Always" communicated well.
H_COMP_3_A_P	How often did patients receive help quickly from hospital staff?	Percent of patients who reported that they "Always" received help as soon as they wanted.
H_COMP_4_A_P	How often was patients' pain well controlled?	Percent of patients who reported that their pain was "Always" well controlled.
H_COMP_5_A_P	How often did staff explain about medicines before giving them to patients?	Percent of patients who reported that staff "Always" explained about medicines before giving it to them.
H_CLEAN_HSP_A_P	How often were patients' rooms and bathrooms kept clean?	Percent of patients who reported that their room and bathroom were "Always" clean.
H_QUIET_HSP_A_P	How often was the area around patients' rooms quiet at night?	Percent of patients who reported that the area around their room was "Always" quiet at night.
H_COMP_6_Y_P	Were patients given information about what to do during their recovery at home?	Percent of patients at each hospital who reported that YES, they were given information about what to do during their recovery at home.
H_HSP_RATING_9_10	How do patients rate the hospital?	Percent of patients who gave their hospital a rating of 9 or 10 on a scale from 0 (lowest) to 10 (highest).
H_RECMND_DY	Would patients recommend the hospital to friends and family?	Percent of patients who reported YES, they would definitely recommend the hospital.

Note. Adapted from "Information for Professionals on Data Collection." Retrieved on April 19, 2010 from World Wide Web: http://www.hospitalcompare.hhs.gov/staticpages/for-professionals/patient-survey-faq.aspx?EntryID=0012

APENDIX B

INTERVIEW QUESTIONS

Part I. ED Characterization

1. How would you classify the location of your ED?
    a. urban
    b. suburban
    c. rural

2. Is your ED:
    a. community
    b. academic
    c. military

3. How many beds does your ED have?

4. What triage acuity system do you use? (e.g. 3-level, 5-level)

5. Do you use "fast track" placement for some patients? If so, what are the criteria for a fast track patient? Which staff member(s) treats fast track patients?

6. Do you use a Computerized Physician Order Entry System (CPOE)?

7. Do you use an Electronic Patient Tracking System (EPTS)?

8. Please indicate whether one or more of the following are staffed in your ED:
    a. Emergency Physician
    b. Emergency Medicine Resident
    c. Emergency Nurse (RN)
    d. Emergency Technician
    e. Physician Assistant
    f. Nurse Practitioner
    g. Radiologist
    h. Radiology Technician
    i. Laboratory Technician
    j. Phlebotomist
    k. Other medical staff (Please specify.)

Part II. Process Definitions

Script: Now we will begin talking through the five processes that I'm interested in. I will ask you to break down each process into steps and tell me *who* performs each step and *where* the step is performed. Please provide as much detail as you can. Also, if these processes vary from time to time (e.g. lab technician makes a courtesy call to nurse with lab results only in severe circumstances), please state how the process is performed under optimal circumstances.

Process 1: Patient Registration

1. Please list the steps involved in the patient registration process, beginning with when the patient walks in to the emergency department. You need not describe the registration process for ambulance arrivals.

   [Allow subject to describe the process]

   [Depending on the amount of detail that is provided, additional questions may include:]

2. Is all patient information collected verbally? Or, does the patient provide some information verbally and complete some forms?
3. How is the patient's medical record generated?
4. How are identification labels generated? (e.g. armband, labeling for medication, lab samples)
5. Who transports the patient from the waiting area to a bed?

Process 2: Blood sample test

1. Please list the steps involved in the process of obtaining a laboratory test of a patient's blood sample, beginning with when the physician orders the test.

   [Allow subject to describe the process]
   [Depending on the amount of detail that is provided, additional questions may include:]

2. How is the physician's test order entered?
3. Is the blood sample collected bed-side? Or, does the patient have to move to a lab testing area to provide the sample?
4. How is the blood sample labeled with patient ID?
5. Where are the samples tested? (e.g. testing area within ED or in hospital's central laboratory)
6. How are test results relayed to physician?
7. How is the test documented on patient chart or EHR?

Process 3: Medication administration

1. Please list the steps involved in the process of administering medication to a patient, beginning with when the physician orders the medication.

   [Allow subject to describe the process]
   [Depending on the amount of detail that is provided, additional questions may include:]

2. How is the physician's medication order entered? (e.g. verbal, CPOE)
3. How does the nurse receive the order for medication?
4. Where is the medicine retrieved from? (e.g. supply room, dispenser)
5. How is the medication order signed off?

Process 4: Imaging

1. Please list the steps involved in the process of a patient receiving an X-ray exam, beginning with when the physician orders the X-ray.

   [Allow subject to describe the process]
   [Depending on the amount of detail that is provided, additional questions may include:]

2. Do you have portable equipment for X-rays?
3. What determines whether the portable equipment is used?
4. Are all non-portable X-rays done in the radiology department, or does your ED have its own (non-portable) imaging equipment?
5. Is the X-ray interpreted by a physician or by a radiologist?
6. When a radiologist interprets the image, how are results relayed back to physician?
7. If the physician interprets the image, how is the image transmitted to him/her? Or, does the physician have to travel to radiology to view the image?

Process 5: Patient Discharge

1. Please list the steps involved in the process of discharging a patient from the ED, beginning with when the physician issues discharge orders.

   [Allow subject to describe the process]
   [Depending on the amount of detail that is provided, additional questions may include:]

2. How does the nurse receive physician's discharge orders?
3. How are written discharge instructions generated and retrieved? (e.g. RN inputs discharge order on unit computer and retrieves automated instructions from unit printer)
4. Does the patient complete any paperwork after receiving discharge instructions?
5. Does the patient complete any billing/collection procedures before leaving the ED?

APPENDIX C

INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

MISSISSIPPI STATE UNIVERSITY

Compliance Division
Administrative Offices
Animal Care and Use (IACUC)
Human Research Protection Program (IRB)
1207 Hwy 182 West, Suite C
Starkville, MS 39759
(662) 325-3496 - fax

Safety Division
Biosafety (IBC)
Radiation Safety
Hazardous Waste
Chemical & Lab Safety
Fire & Life Safety
70 Morgan Avenue
Mississippi State, MS 39762
(662) 325-8776 - fax

http://www.orc.msstate.edu
compliance@research.msstate.edu
(662) 325-3294

July 20, 2010

Laura Ruff
Industrial and Systems Engineering
MAILSTOP 9542
MS State, MS 39762

RE: IRB Study #10-202: Investigating Core Process Complexity in Hospital Emergency Departments

Dear Ms. Ruff:

The above referenced project was reviewed and approved via administrative review on 7/20/2010 in accordance with 45 CFR 46.101(b)(2). Continuing review is not necessary for this project. However, any modification to the project must be reviewed and approved by the IRB prior to implementation. Any failure to adhere to the approved protocol could result in suspension or termination of your project. The IRB reserves the right, at anytime during the project period, to observe you and the additional researchers on this project.

Please note that the MSU IRB is in the process of seeking accreditation for our human subjects protection program. As a result of these efforts, you will likely notice many changes in the IRB's policies and procedures in the coming months. These changes will be posted online at http://www.orc.msstate.edu/human/aahrpp.php. The first of these changes is the implementation of an approval stamp for consent forms. The approval stamp will assist in ensuring the IRB approved version of the consent form is used in the actual conduct of research.

Please refer to your IRB number (#10-202) when contacting our office regarding this application.

Thank you for your cooperation and good luck to you in conducting this research project. If you have questions or concerns, please contact me at cwilliams@research.msstate.edu or call 662-325-5220.

Sincerely,

[For use with electronic submissions]

Christine Williams
IRB Compliance Administrator

cc: Lesley Strawderman

Office of Regulatory Compliance & Safety • Post Office Box 6223 • Mississippi State, MS 39762

APPENDIX D

INFORMED CONSENT SCRIPT

Verbal Informed Consent Script

Investigating Core Process Complexity in Hospital Emergency Departments
Laura Ruff

I am a graduate student in the Department of Industrial and Systems Engineering at Mississippi State University. I am conducting a study that will investigate five core processes in hospital emergency departments (EDs): patient registration, medication administration, laboratory testing, radiology imaging, and patient discharge. Specifically, I'm interested in the personnel, information transfers, communication and collaboration, documentation, and travel involved in these processes.

Before we begin, I would like to take a minute to explain why I am inviting you to participate and what I will be doing with the information you provide to me. Please stop me at any time if you have questions. After I've told you a bit more about the interview, you can decide whether or not you would like to participate.

I am doing this research as part of my graduate studies. I will be interviewing twelve staff members at twelve different hospital EDs and will use this information as the basis for my Master's Thesis. I may also use this information in articles that might be published, as well as in academic presentations.

Participation should take about one hour. You will be asked to provide some information to characterize your ED (e.g. number of beds, staff mix, etc.) and describe how five processes are typically performed in your hospital. Any personal identifiers, including your name and hospital's name, will *not* be used in analysis or writing of results. Identifiers will be replaced by pseudonyms in all writings, publications, and presentations to protect your confidentiality. The data will be stored on a password protected computer in the Human Systems lab at MSU.

Your participation is purely voluntary. If at any time and for any reason, you would prefer not to answer a question, please feel free not to. If at any time you would like to stop participating, please tell me. We can take a break, stop and continue at a later date, or stop altogether. You will not be penalized in any way for deciding to stop participation at any time.

I would like to audio record this interview so as to make sure that I remember accurately all the information you provide. I will keep the audio files on a password protected computer and they will only be used by researchers listed on this form. If you prefer to participate without being recorded, please let me know.

If you have questions, feel free to ask them now. If you have questions later, you may contact Laura Ruff at (601) 218-4654 or lcr48@msstate.edu. Contact information for other researchers is found below.

If you have any questions about your rights as a participant in this research, you can contact the MSU Regulatory Compliance Office at 662-325-3294.

Are you interested in participating in this study?

MSU IRB
Approved: 7/20/10
Expires: –/–/–

APPENDIX E

RAW DATA

Table E.1

Complexity Scores for Registration Process

Hospital	PI_{1j}	SI_{1j}	RT_{1j}	DT_{1j}	IN_{1j}	PS_{1j}	PE_{1j}	PT_{1j}	IT_{1j}	CD_{1j}	DP_{1j}	TS_{1j}	PAT_{1j}	PRO_{1j}	COM_{1j}
1	1	1	1	0	3	3	2	2	2	2	1	5	0.32	0.49	0.40
2	1	1	1	0	3	5	2	2	2	3	1	6	0.36	0.55	0.45
3	1	2	2	0	3	4	3	1	0	3	1	5	0.43	0.44	0.44
4	3	2	2	0	3	6	5	3	2	3	2	7	0.59	0.80	0.69
5	2	2	3	0	3	6	4	3	2	3	1	8	0.57	0.70	0.64
6	3	2	3	0	5	8	5	3	3	4	1	9	0.74	0.83	0.78
7	3	1	2	0	3	5	3	3	3	3	2	7	0.51	0.77	0.64
8	1	3	4	0	3	7	3	1	4	4	1	8	0.63	0.71	0.67
9	3	2	3	0	3	7	5	4	3	3	1	9	0.65	0.83	0.74

Table E.2

Complexity Scores for Laboratory Process

Hospital	PI_{2j}	SI_{2j}	RT_{2j}	DT_{2j}	IN_{2j}	PS_{2j}	PE_{2j}	PT_{2j}	IT_{2j}	CD_{2j}	DP_{2j}	TS_{2j}	PAT_{2j}	PRO_{2j}	COM_{2j}
1	2	0	0	0	1	1	3	1	3	3	1	7	0.44	0.70	0.57
2	3	0	0	0	1	1	3	2	3	3	1	9	0.50	0.78	0.64
3	2	0	0	0	1	1	3	2	1	1	1	7	0.44	0.58	0.51
4	2	0	0	0	1	1	4	1	4	3	1	8	0.44	0.80	0.62
5	2	0	0	0	1	1	3	2	1	1	1	7	0.44	0.58	0.51
6	3	0	0	0	1	1	3	4	3	3	1	9	0.50	0.86	0.68
7	3	0	0	0	1	1	3	2	4	4	1	9	0.50	0.86	0.68
8	3	0	0	0	1	1	4	2	4	3	1	10	0.50	0.88	0.69
9	2	0	0	0	1	1	2	3	3	3	1	8	0.44	0.76	0.60

Table E.3

Complexity Scores for Medication Administration Process

Hospital	PI_{3j}	SI_{3j}	RT_{3j}	DT_{3j}	IN_{3j}	PS_{3j}	PE_{3j}	PT_{3j}	IT_{3j}	CD_{3j}	DP_{3j}	TS_{3j}	PAT_{3j}	PRO_{3j}	COM_{3j}
1	2	0	0	0	1	2	2	2	1	2	1	7	0.50	0.84	0.67
2	2	0	0	0	0	2	2	2	2	2	1	8	0.33	0.91	0.62
3	2	0	0	0	1	2	2	2	1	1	0	7	0.50	0.59	0.54
4	2	0	0	0	0	2	2	2	1	1	1	7	0.33	0.76	0.54
5	2	0	0	0	0	2	2	2	3	1	1	7	0.33	0.87	0.60
6	2	0	0	0	1	2	2	2	2	2	1	8	0.50	0.91	0.71
7	2	0	0	0	1	2	2	2	2	2	1	10	0.50	0.94	0.72
8	2	0	0	0	1	2	2	2	2	2	1	10	0.50	0.94	0.72
9	2	0	0	0	1	2	2	2	2	2	1	7	0.50	0.89	0.70

Table E.4

Complexity Scores for Radiology Process

Hospital	PI_{4j}	SI_{4j}	RT_{4j}	DT_{4j}	IN_{4j}	PS_{4j}	PE_{4j}	PT_{4j}	IT_{4j}	CD_{4j}	DP_{4j}	TS_{4j}	PAT_{4j}	PRO_{4j}	COM_{4j}
1	3	0	1	1	1	3	3	2	3	2	1	9	0.83	0.79	0.81
2	3	0	1	1	1	3	4	2	3	1	1	9	0.83	0.78	0.80
3	3	0	1	1	1	3	3	2	3	1	1	8	0.83	0.72	0.78
4	3	0	1	1	1	3	4	2	3	2	1	9	0.83	0.83	0.83
5	3	0	1	1	1	3	2	2	3	1	1	8	0.83	0.68	0.75
6	3	0	1	1	1	3	3	2	3	2	1	8	0.83	0.77	0.80
7	3	0	1	1	1	3	4	3	4	3	1	10	0.83	1.00	0.92
8	3	0	1	1	1	3	3	2	3	3	1	9	0.83	0.84	0.84
9	3	0	1	1	1	3	4	2	3	2	1	9	0.83	0.83	0.83

Table E.5

Complexity Scores for Discharge Process

Hospital	PI_{5j}	SI_{5j}	RT_{5j}	DT_{5j}	IN_{5j}	PS_{5j}	PE_{5j}	PT_{5j}	IT_{5j}	CD_{5j}	DP_{5j}	TS_{5j}	PAT_{5j}	PRO_{5j}	COM_{5j}
1	2	0	0	0	1	3	2	0	2	1	0	6	0.35	0.40	0.38
2	2	0	0	0	1	3	2	0	2	2	0	6	0.35	0.46	0.40
3	2	1	1	1	2	4	3	0	1	0	0	7	0.97	0.37	0.67
4	2	1	1	1	2	4	3	0	3	1	0	7	0.97	0.53	0.75
5	2	0	0	0	1	4	2	0	3	2	0	8	0.38	0.56	0.47
6	2	0	0	0	1	4	2	0	2	1	0	6	0.38	0.40	0.39
7	2	0	0	0	1	5	2	0	3	3	0	7	0.42	0.59	0.50
8	2	0	0	0	1	4	2	0	3	3	0	8	0.38	0.61	0.50
9	2	0	0	0	1	4	2	0	2	2	0	7	0.38	0.48	0.43

Table E.6

Quality Scores

Hospital	Patient satisfaction	Process of Care Quality	Overall Quality
1	84.6	89.08	86.64
2	63.4	97.58	82.35
3	71.4	90.33	81.95
4	67.2	93.58	81.75
5	71.7	89.25	81.32
6	62.7	93.50	80.13
7	80.00	77.17	79.08
8	73.1	79.42	77.87
9	79.2	64.33	72.84

APPENDIX F

PROCESS DIAGRAMS

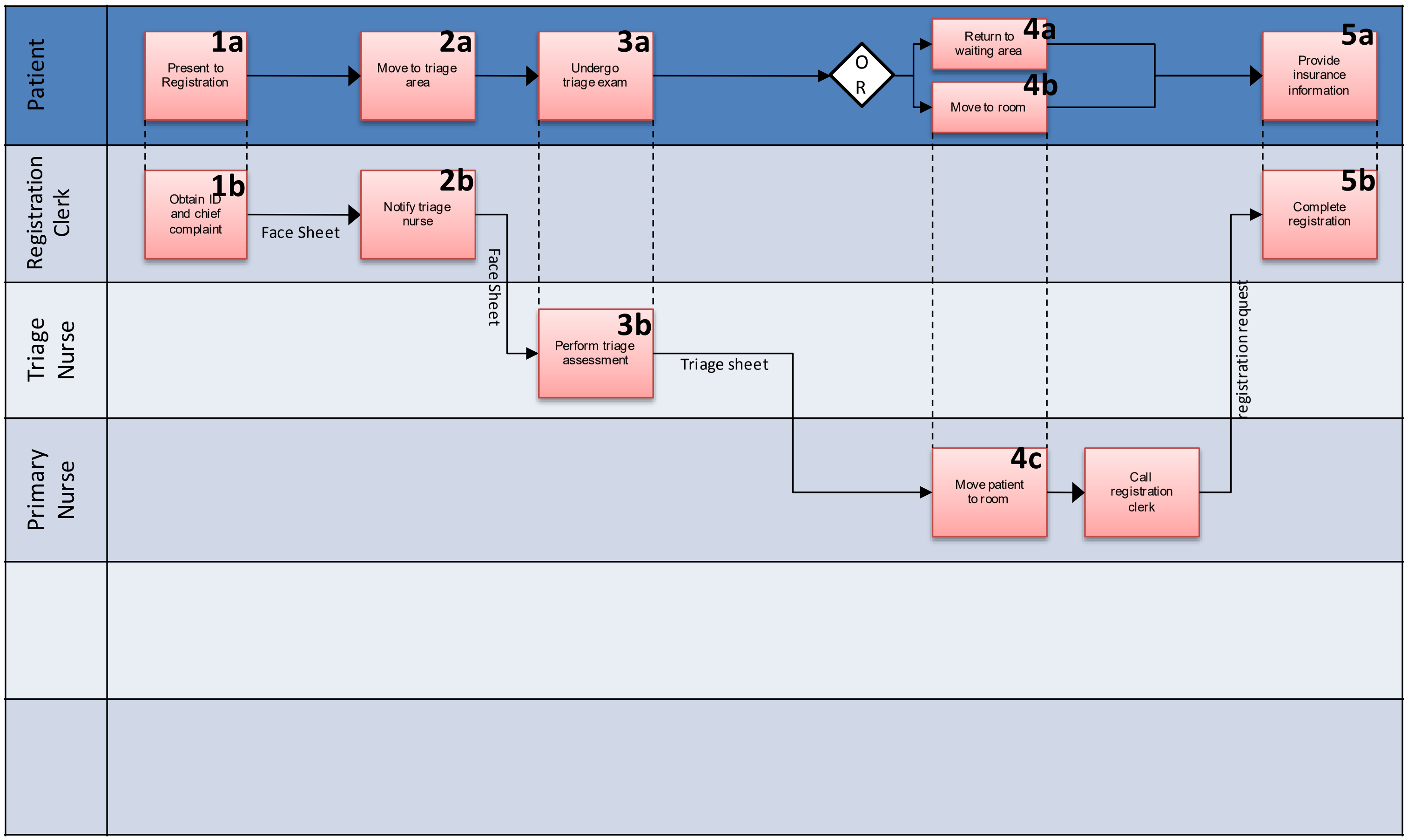

Figure F.1 ED Registration Process Map

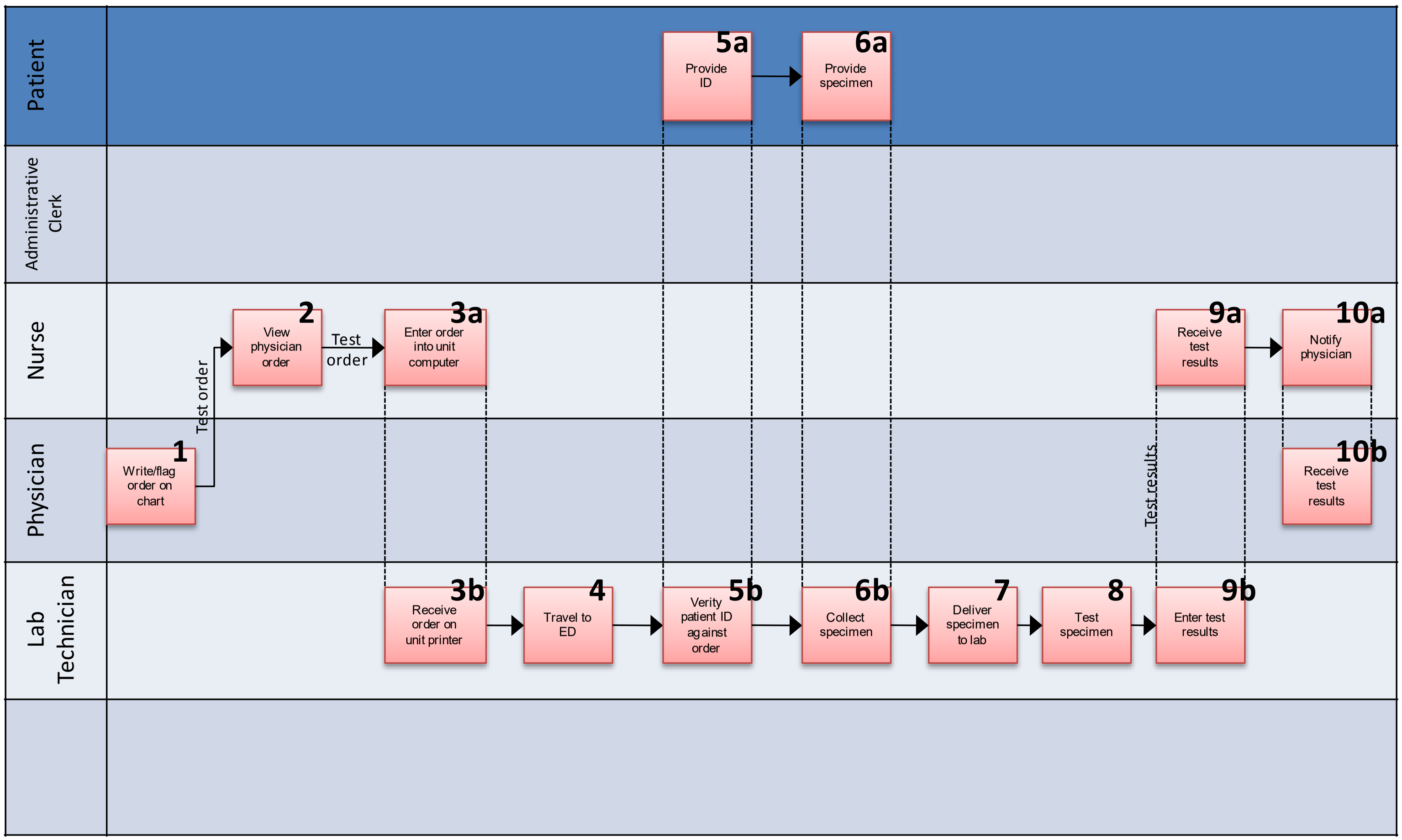

Figure F.2 ED Blood Sample Testing Process Map

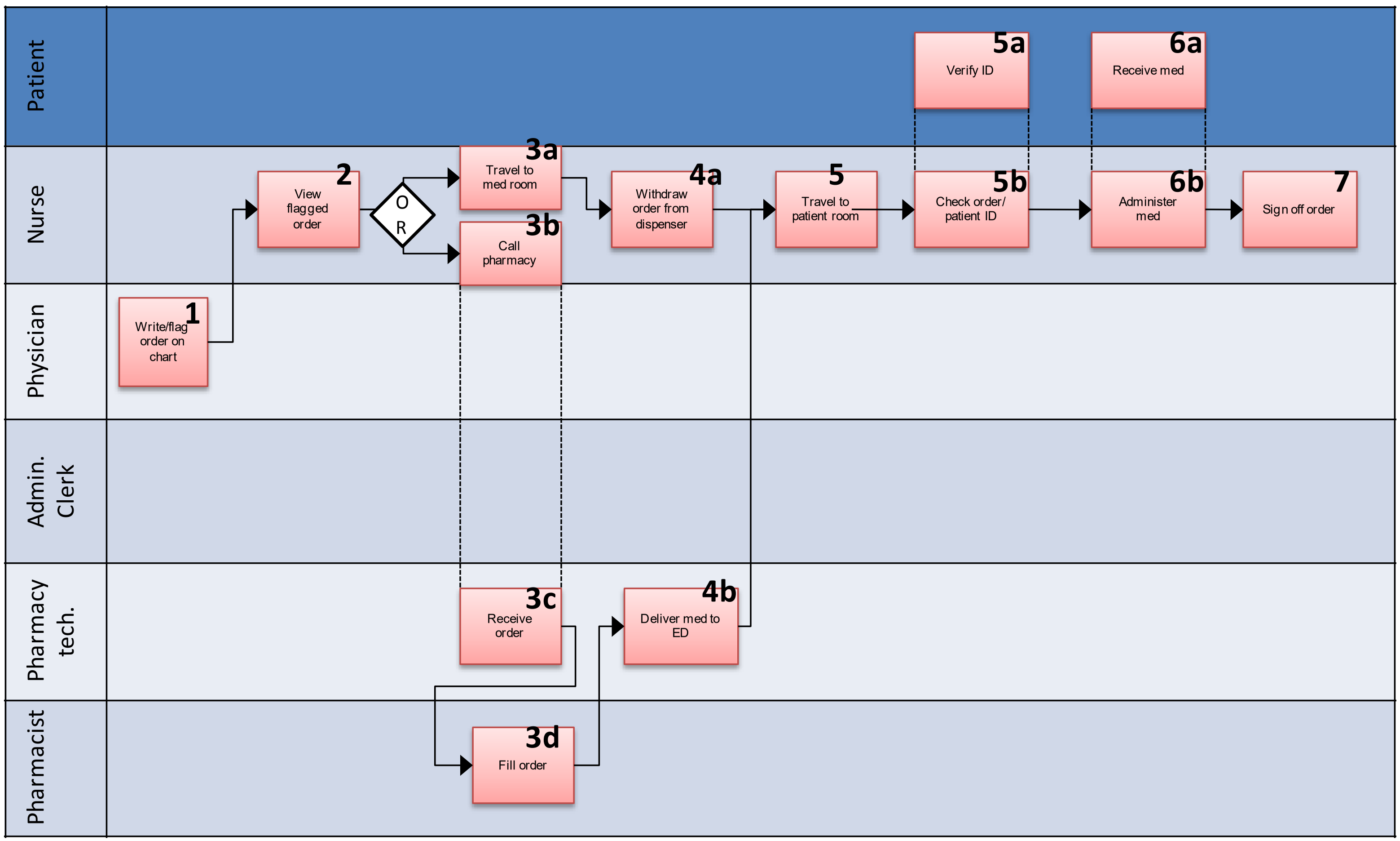

Figure F.3 ED Medication Administration Process Map

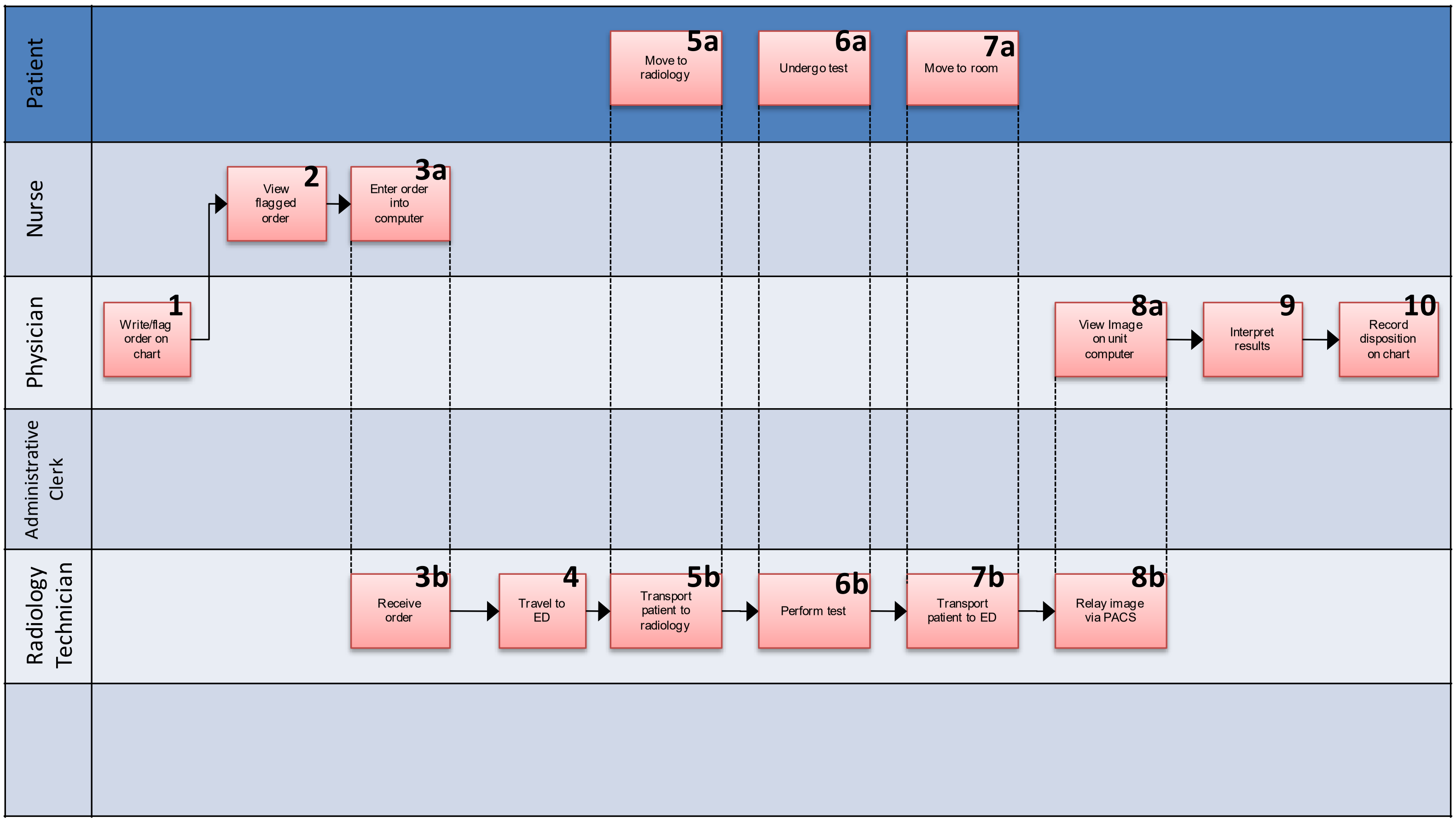

Figure F.4 ED X-ray Imaging Process Map

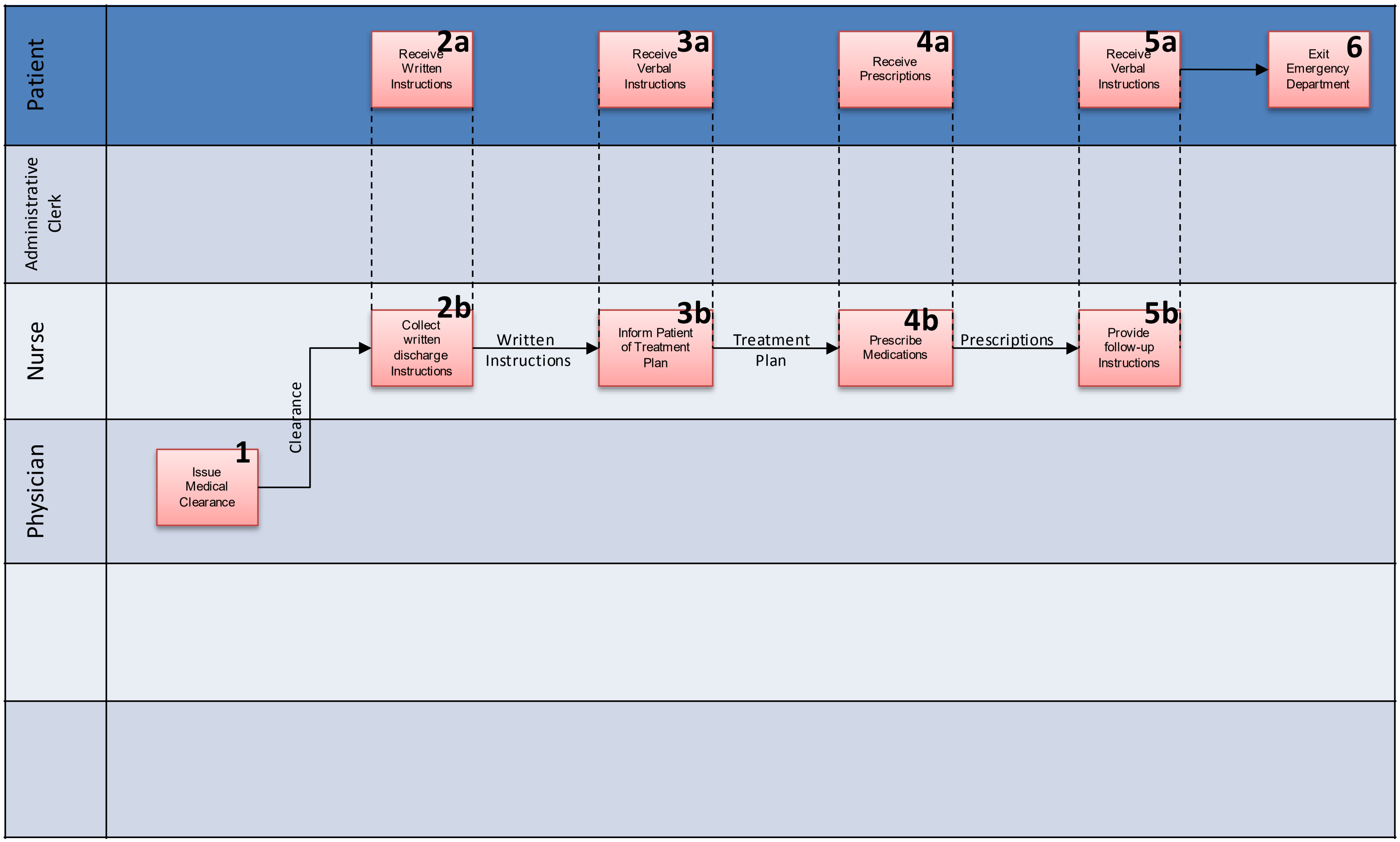

Figure F.5 ED Discharge Process Map