ERRORS AND ADVERSE CONSEQUENCES AS A RESULT OF INFORMATION TECHNOLOGY USE IN HEALTHCARE: AN INTEGRATED REVIEW OF THE LITERATURE

Christopher Kiess

Submitted to the faculty of the School of Informatics in partial fulfillment of the requirements for the degree of
Master of Science in Health Informatics
Indiana University

December 2012

Accepted by the Faculty of Indiana University,
in partial fulfillment of the requirements for the degree of Master of Science
in Health Informatics

Master's Thesis
Committee

_____
Josette Jones, Ph.D., Committee Chair

_____
Jason Saleem, Ph.D., M.S.

_____
Katherine Schilling, MLS, Ed.D.

Our greatest achievements in life do not occur in a vacuum, nor are they products of our own toil. They are accomplished through the support, nurturing and contributions of those surrounding us in our lives and those *who have* surrounded us. As such, this work is dedicated to the following:

My daughter, Mary Kiess, who allowed her father the solitude to pursue his passion in study.

My loving wife, Barbara Albee, who has supported me through each step in this degree.

My parents, Joe and Donna Kiess, who inspired me early in life.

My sister, Jennifer, who helped a single father more than once in rearing his daughter.

Table of Contents

List of Tables

List of Figures

Abstract

Health Information Technology (HIT) has become an integral component of healthcare today. The HITECH Act (2009) and Meaningful Use objectives stand to bring wide-sweeping adoption and implementations of HIT in small, medium and large sized healthcare organizations across the country. Though recent literature has provided evidence for the benefits of HIT in the profession, there have also been a growing number of reports exploring the adverse effects of HIT. There has not, however, yet been a systematic account of the adverse effects of HIT in the healthcare system. The current push for HIT coupled with a lack of critical appraisal of the potential risks of implementation and deployment within the medical literature has led to a general unquestioning and unregulated acceptance of the implementation of technology in medicine and healthcare as a positive addition with little or no risk. While the benefits of HIT are clear, a review of the existing studies in the literature would provide a holistic vision of the adverse effects of HIT as well as the types and impact within the nation's health care system to inform future HIT development and implementation. The development of a general understanding of these adverse effects can serve as a review and summary for the use of informatics professionals and clinicians implementing HIT as well as providing future direction for the industry in HIT implementations. Additionally, this study has value for moving forward in informatics to develop frameworks for implementation and guidelines and standards for development and regulation of HIT at a federal level.

This study involves the use of an integrative literature review to identify and classify the adverse effects of HIT as reported in the literature. The purpose of this study is to perform an integrative review of the literature to 1) identify and classify the adverse effects of HIT; 2) determine the impact and prevalence of these effects; 3) identify the recommended actions and best practices to address the negative effects of HIT.

This study analyzed 18 articles for HIT-induced error and adverse consequences. In the process, 228 errors and/or adverse consequences were identified, classified and represented in an operational taxonomic schema. The

taxonomic representation consisted of 8 master categories and 30 subcategories. Additionally, the prevalence and impact of these errors were evaluated as well as recommendations and best practices in future systems design.

This study builds on previous work in the medical literature pertaining to HIT-induced errors and adverse consequences and offers a unique perspective in analyzing existing studies in the literature using the integrative review model of research. It is the first work in combining studies across healthcare technologies and analyzing the adverse consequences across 18 studies to form a cohesive classification of these events in healthcare technology.

Introduction

Problem Statement

The effective implementation and deployment of health information technology in healthcare has increasingly become a high priority for the nation. Within the past decade, a number of agencies have called for the adoption of technologies to aid in automating and supporting the healthcare system. (Kohn, Corrigan, & Donaldson, 2000; Reid, Compton, Grossman, & Fanjiang, 2005). Despite this call for action, adoption rates of health information technology remain low (Furukawa, Raghu, Spaulding, & Vinze, 2008; Jha et al., 2009; Pedersen & Gumpper, 2008) resulting in a massive number of health care entities as potential future adopters. Evidence of the benefits of HIT has been reported in the literature (Bates et al., 1998; Chaudhry et al., 2006; Poon et al., 2010) and the benefits of HIT are clear. But there is also evidence to the contrary of these reports (Ash et al., 2007b; Bates, 2005; Campbell, Sittig, Guappone, Dykstra, & Ash, 2007; Chaudhry et al., 2006; Himmelstein, Wright, & Woolhandler, 2010) - evidence that has begun the exploration of errors and adverse consequences of HIT. There has not, however, yet been a systematic account of HIT-induced errors in the healthcare system and the current push for HIT coupled with a lack of a critical appraisal of the potential risks of implementation (e.g. a review of the literature and existing studies) and deployment within the medical literature has led to a general unquestioning and unregulated acceptance of the implementation of technology in medicine and healthcare as a positive addition with little or no risk. (Karsh, Weinger, Abbott, & Wears, 2010) Given the potential spread of HIT initiatives in the nation coupled with the American Recovery and Reinvestment Act, the healthcare system stands to implement HIT more widely and at a quicker rate than ever. While automation in healthcare and HIT is beneficial, the wide spread adoption of HIT across the nation without properly assessing the risks and errors of past experiences potentiates an equally widespread epidemic of HIT-related injuries, patient safety risks and medical failures. The importance in

understanding HIT-induced errors and adverse consequences has also been underscored in recent literature as a dire problem that must be addressed and understood in moving forward with HIT. (Coiera, Aarts, & Kulikowski, 2012; Karsh et al., 2010; Sittig & Singh, 2011) There is currently a movement to address these issues. A recent advisory report from the Institutes of Medicine (IOM), "Health IT and Patient Safety: Building Safer Systems for Better Care," makes specific recommendations regarding the safety concerns in future development of HIT and highlights findings of HIT-induced errors and unintended consequences within the medical literature. (Safety, Technology, & Medicine, 2012) Understanding the implications of HIT and the potential for adverse effects in a complex system can aid in minimizing errors and preventing harm to the patient and healthcare professional. Moreover, the recognition of HIT-related errors and HIT-related adverse effects as well as a systematic approach to identifying and categorizing them can contribute to future efforts in standardization of development, regulation and implementation of HIT.

Purpose of Study

The purpose of this study is to perform an integrative review of the literature to 1) identify and classify the adverse effects of HIT; 2) determine the impact and prevalence of these effects; 3) and identify the recommended actions and best practices to address the adverse effects of HIT.

Importance of the Study

The importance of this study lies in gaining a holistic vision of the adverse effects of HIT, the types of adverse effects and the impact of these effects within the nation's health care system to inform future HIT development and implementation. Moving forward and implementing technologies and automation in medicine is critical to the success of medicine in the future. A development of a general understanding of these adverse effects can serve as a review and summary for the use of informatics professionals and clinicians implementing HIT. Additionally, this study provides value for moving forward in informatics to

develop frameworks for implementation and possible guidelines and standards for development and regulation of HIT at a federal level.

Background and Literature Review

Introduction

This study involves the use of an integrative literature review to identify and classify HIT-induced errors and adverse consequences as reported in the literature. As such, two preliminary topics are covered within this section – the integrative literature review and defining a medical error. A third and primary topic is also addressed – the adverse consequences of HIT and HIT-induced errors as reported in the medical literature.

The Integrative Literature Review

The integrative review is a research design primarily used in nursing research that has emerged as a result of evidence-based practice (EBP) where studies with differing methodologies are often compared and contrasted to develop and synthesize results. (Beyea & Nicoll, 1998) It differs from the systematic review and meta-analysis in this respect and in the respect that it generally does not attempt to rank order or quantify the results. However, in certain instances qualitative results are analyzed separately from those results that can be quantitatively analyzed and the end results are presented for the different analyses. The advantage to using an integrative review design is that it allows for different study methodologies to be evaluated, compared and reported upon. (Beyea & Nicoll, 1998; Cooper & Cooper, 1998; Rodgers & Knafl, 2000; Whittemore & Knafl, 2005) The challenge in using this design is there has not been complete consensus among scholars on the methodology for the data analysis phase of integrated reviews. There is also not a clear consensus on what qualifies as an integrative review. Moreover, the evaluation of diverse sources of qualitative data with varying methodologies is a complex undertaking in itself not devoid of its own set of challenges. The nature of these studies is such that they do not lend well to the ranking or scoring procedures commonly used in reviews.

Finally, reaching a consensus on what represents quality in any review - whether systematic or integrative - presents a challenge.

Defining a Medical Error

The subject of what constitutes a medical error or medication error has received ample attention in the literature. (Kalra, 2004; Lisby, Nielsen, Brock, & Mainz, 2010; Tamuz, 2004) Within the medical industry there is a wide degree of interpretation in terms of what constitutes an error and a fair amount of disagreement as to what a medical error is or is not. (Hofer, Kerr, & Hayward, 2000) Hofer and colleagues write of the complexity in simply defining what an error is and how it is determined an error actually occurred. Their findings suggest a vague notion of what an error is and problems in the consistency of definitions. (2000) Lisby and colleagues came to the same conclusion when evaluating medication errors in a systematic review covering 45 studies. (Lisby et al., 2010) Given the propensity of differing definitions regarding what is and is not a medical error or medication error, it becomes an exercise in semantics to define an *HIT-related error*. Imposing a strict definition of error for this study becomes problematic for two reasons. First, there is clearly no agreed upon definition that could be employed. In the systematic review noted above, 26 of the 45 articles reviewed included significant variations in definitions. (2010) Second, there could be items that are not truly an error in nature. All unintended consequences are not errors. For example, Joan Ash reports on shifts in power as a result of HIT implementation. (Ash, Sittig, Campbell, Guappone, & Dykstra, 2006) A shift in power due to HIT implementation does not necessarily represent an error or even a potential error. This study would either be excluded or placed in a different category if strict definitions of errors were to be imposed. Thus this thesis used the definition specifically applied to HIT-induced errors proposed by Dean Sittig and Hardep Sing: (2011)

> "[an] HIT-related error occurs anytime HIT is unavailable for use, malfunctions during use, is used incorrectly by someone, or when HIT

interacts with another system or component incorrectly, resulting in data being lost or incorrectly entered, displayed or transmitted."

In addition, issues associated with adverse consequences, unintended consequences and sociotechnical problems associated with HIT are also included within this definition. They are not errors – as described above – but either potentiate an error (in most cases) or are important in their own right as adverse social issues resulting from less than desirable HIT implementations or design.

Adverse Consequences of HIT

There have been a number of studies and publications investigating or reporting on the adverse effects of HIT. One of the largest bodies of research comes from studies evaluating the unintended consequences of HIT. (Ash, Berg, & Coiera, 2004; Ash et al., 2006, 2007; Ash, Sittig, Dykstra, Campbell, & Guappone, 2007, 2009; Ash et al., 2007b; Campbell, Sittig, Ash, Guappone, & Dykstra, 2006; Harrison, Koppel, & Bar-Lev, 2007; Wachter, 2006) These studies have largely been attempts to understand sociotechnical relationships in healthcare and how these relationships often result in unforeseen consequences. They exist as an emerging inquiry into the unintended consequences resulting from the implementation of technology and the interaction of healthcare professionals with new technologies.

The earliest discussions of the unintended consequences in the healthcare literature do not focus on errors, but rather administrative aspects of HIT. One early article analyzing the benefits and detriments of electronic medical records, (Silverman, n.d.) cited two primary problems with electronic medical records – lack of privacy and the costs associated with implementation and upkeep. Though this latter category is reported on in later works by Joan Ash and her colleagues, (Ash et al., 2006; Ash et al., 2007a; Dykstra et al., 2009) Silverman's article was brief and, at the time it was published, speculative. Wachter used the term "unforeseen consequences" in a general assessment of computerization in healthcare but maintained a focus on quality and safety in healthcare from primarily an administrative viewpoint. (Wachter, 2006) It was Ash and her

colleagues who spearheaded the research on unintended consequences with her studies beginning in 2003 (Ash et al., 2004) and explored unintended consequences first as part of research including three different countries across the United States, Europe and Australia. Ash's research into the problems associated with the implementation of information technology resulted largely in a set of descriptive categories. These categories were essential for understanding the effects of technology both good and bad. The results were the first attempt at categorizing the errors resulting from the unintended consequences of implementation of technology. However, they are far from a complete accounting of the adverse effects of HIT in the medical literature. The intent of Ash's initial study concerned gathering qualitative data in institutions using Patient Care Information Systems. In gathering and analyzing the data, the observers began to discover patterns indicating there existed possibilities of errors occurring within these systems or there were attitudes reflecting this knowledge amongst those interviewed. (2004) This initiated a series of related studies to both analyze the existing data from new perspectives and obtain more data. (Ash et al., 2006, 2007; Ash et al., 2007, 2009; Ash et al., 2007a, 2007b) The body of work Ash and her colleagues produced provided insight into:

- The types or categories of unintended consequences
- Types of unintended consequences specific to clinical decision support systems (CDS) and Computerized Provider Order Entry (CPOE)
- Sociological consequences of the implementation of HIT
- An attempt to quantify the importance of the types of unintended consequences
- A picture of the extent or prevalence of unintended consequences
- Solutions and implementation recommendations

Ash and her colleagues later developed an 8-question survey designed to determine the extent or prevalence of the types of unintended consequences and to determine the overall level of importance of each type to hospitals with implemented Computerized Provider Order Entry. (2009) One hundred and

seventy-six interviews were conducted via telephone. Rated the highest in terms of importance were system demands on the staff, communication and workflow issues. The lowest rating went to shifts in power and new types of errors that HIT could cause. Most interesting to note is there did not appear to be any correlation between the length of time each hospital had owned the CPOE system and unintended consequences as a result of the system. This suggests adverse effects can exist in systems regardless of how long they have been using HIT underscoring the importance of this research. Ash and colleagues also noted there were both positive and negative unintended consequences involved in implementation of CPOE and that hospitals can either work to avoid the negative unintended consequences or simply accept them as part of developing a new system.

Ash and her colleague's work serves as a body of research for informing HIT-related adverse effects. But as noted above, it does not serve as a complete representation nor a singular body of work on the subject. It was also largely informed through the use of qualitative methods – specifically, ethnography and surveys. Other studies exist that have used quantitative methods and other forms of qualitative data collection.

Harrison investigated unintended consequences from a sociotechnical perspective (Harrison et al., 2007) evaluating five interactive sociotechnical analysis types. However, this research was focused on filtering the unintended consequences and HIT-related errors through an analytical framework and not classifying or evaluating the types of errors. The authors attempted to construct a model for the prevention of HIT-induced errors using the framework.

The bulk of research in HIT-induced errors can be found in the literature evaluating CPOE systems. Ash and her colleagues work was central to the CPOE, but investigated the unintended consequences. A number of studies have been published in recent years evaluating the types of errors found in a given CPOE system.

One study performed by Yan Han and colleagues (Han et al., 2005) originating in the Children's Hospital of Pittsburgh reported an increase of

3.77percent in mortality after the implementation of a CPOE. This study generated concern in the field of medicine because it was an unexpected outcome of HIT. The study gained such attention it was later commented on by Dean Sittig and Joan Ash in a commentary published in the same journal. (Sittig, Ash, Zhang, Osheroff, & Shabot, 2006) A study published that same year, however, showed a significant decrease in mortality after implementation of a CPOE. (Del Beccaro, Jeffries, Eisenberg, & Harry, 2006) An expert panel was then constructed to evaluate the two studies and develop an understanding of the differences in results. (Ammenwerth et al., 2006) The primary findings showed the two studies were difficult to compare due to differing study designs and sampling. Also, the Han study had implemented their CPOE in a six-day time period rather than using a slow implementation process. The primary recommendation of this paper was to ensure a sociotechnical approach was taken in implementation that would recognize the differences within organizations and to ensure future informatics professionals are educated in these approaches.

Ross Koppel and his colleagues conducted a study using both quantitative and qualitative methods to examine the effects of CPOE on medication errors. (Koppel et al., 2005) Their study resulted in finding 22 different classes of errors, which they then divided into two large categories –interface issues and information errors due to faulty systems implementation and integration. The information related errors largely revolved around medication administration and medication reconciliation. Some of these errors underscored a clear lack of foresight into who would use the system and how it would (or should) be used. For example, dosing of medications was set from a pharmacy purchasing perspective so that the medications were listed in the system as they were ordered from suppliers. This meant a single dose could be more or less than what was standard for the physician or clinic. This resulted in both under and overdosing patients. There were also scheduling problems with the cancellation of medication orders and renewal of medications. Within the system cancelling a medication was a different process than medication renewal (lack of consistency) meaning the system was prone to errors if the physician forgot to complete the entire

process. An alert process for allergy medicines failed to notify the physician until after the order was sent meaning in a highly interruptive environment, the alert could possibly never be seen. Errors with the interface included unclear log-on and log-off procedures (lack of feedback) where physicians could potentially enter orders under another physician's id. Other errors included simultaneous charting, improper alerts and errors in which the procedures in the institution are subjugated or ignored. The study findings confirmed what Ash and colleagues (Ash et al., 2007a) found and what Ammenwerth and colleagues (Ammenwerth et al., 2006) recommend – sociotechnical approaches are necessary to address these errors prior to implementation.

Zahra Niazkhani and colleagues conducted a qualitative study focused on the workarounds using a CPOE system. (Niazkhani, Pirnejad, van der Sijs, & Aarts, 2011) The majority of workarounds identified through their research were related to system location. In the study setting, systems were not available at bedside. This caused cognitive overload forcing professionals to memorize orders and documentation elements until they could access a system. In addition, there were several equipment related problems to include issues with printers not printing the forms and labels, which in some instances could cause missed orders. Communication problems were noted as well. Orders in the system would often be placed with no verbal communication to the recipient. In many instances, nurses may not understand physicians' orders when reading them after submission forcing them to contact the physician and delaying treatment. Other communication problems were the system's lack of notification for high priority orders. A common problem with many systems in healthcare is the illusion of communication reported on in a number of studies (Ash et al., 2004; Campbell et al., 2006; Patterson, 2002) where healthcare professionals assume that placing an order in the system equates to the order being acted upon or carried out. Nizakhani and colleagues also found problems with workflow where the system did not match the flow of work in a given clinic or medical setting. For example, verbal orders were not supported in the system and the system did not allot for emergency situations where orders could be entered at a later time with the

time/date stamp adjusted to reflect the actual time of medication administration. Finally, there were a number of issues involving information design or interface design – specifically with labels. Labels for charts and orders were not designed well and difficult to read with same-sized font or hard to read font size. In addition, they were highly detailed and included too much information. These issues all combined synergistically to cause a number of workarounds for the CPOE system and provide numerous examples of shortcomings in the design of the system.

Another study investigated the use of CPOE in pediatric units. (Walsh et al., 2006) The authors studied 352 randomly selected pediatric admissions and retroactively reviewed these admissions for errors. They discovered 104 total errors, 20 of which were computer-related – 7 of which were considered serious. The majority of the errors discovered involved problems associated with poor interface design. Selection of the wrong medication via the dropdown menu was common with juxtaposition errors – wrong dose, wrong medication or wrong patient selected – at the forefront of the causes. Duplicate medication errors, keypad entry errors and problems with the default selection of order sets were described as well. This study represented a very small set of computer-related errors in the use of CPOE, but does confirm other findings related to HIT-induced errors and adverse effects in the use of CPOE. (Ash et al., 2004; Ash et al., 2007; Campbell, Guappone, Sittig, Dykstra, & Ash, 2009; Campbell et al., 2006; Koppel et al., 2005; Santell, Kowiatek, Weber, Hicks, & Sirio, 2009; Wetterneck et al., 2011)

John Santell and his colleagues retroactively reviewed MEDMARX data to evaluate CPOE-related errors submitted to the database for 693 unique facilities. (Santell et al., 2009) They discovered a number of problems discussed previously in this review to include juxtaposition errors, errors in dosing due to incorrect algorithms, dosing and omission errors as well as unclear computer generated labels as discussed above. In addition, they discovered a number of errors resulting from distraction or interruption, inconsistencies in measurements (height and weight), improperly trained temporary staff, false alerts and wrong

dates and times entered into the system. This study concentrated on "non-prescribers" and adds numerous error types to the CPOE error-related literature.

Tosha Wetterneck and her colleagues conducted an analysis of duplicate medication errors in a CPOE system with CDS in two intensive care units (ICUs). They analyzed the system across 4,147 patient days prior to implementation and 4,013 after implementation discovering a 5.5 percent increase in errors post-implementation. The problems they cite in system design include poor alert design, alert fatigue, system errors in detecting and/or preventing duplicate orders, an inability to view a patient's medication history in a single place (leading to errors in prescribing) and system rigidity in allowing different order routes to be selected and changed during the patient's care. In addition, they discovered problems with the interface design and default order sets leading to duplicate medication orders and thus errors in overprescribing. The default order set allows multiple prescriptions to be placed in a single keystroke. The problem occurs when the system does not recognize a duplicate order coming from the default set.

While CPOE represents the bulk of the research in HIT-induced errors, Bar Code Medication Administration (BCMA) is a closely related technology receiving less attention in the medical literature. There have been relatively few rigorous studies analyzing the errors and adverse consequences resulting from the use of these systems. The majority of the literature surrounding the use of BCMA systems focuses on associated misuse or workarounds.

Koppel and colleagues conducted a study to evaluate the prevalence, causes and problems associated with patient safety as a result of BCMA workarounds. (Koppel, Wetterneck, Telles, & Karsh, 2008) This study represents the richest set of data acquired on the use of BCMA systems in the medical literature. In it, the authors identify 15 types of BCMA workarounds and 31 causes for the workarounds. Their research spanned across five hospitals using BCMA. They utilized various methods of qualitative data collection to include log analysis, interviews and observation methods. The study identified a number of interface and design issues with the technology including imperceptible error beeps (or beeps that indicated an error and could not be heard in a loud

environment), multiple screens needed to complete a single action, being timed out due to a preset administration time and inability to find the right information in the system. In addition, there were clear failures of the system that were problematic including connectivity issues, BCMA failure, barcode defects and problems reading barcodes or missing barcodes. The fact that BCMA extends the amount of time related to administering a medication leads to user dissatisfaction and problems in the efficiency of workflow. There were also issues in training where employees did not value the system for its safety impact or even realize the safety measures the system puts in place. A final issue was the rigidity of the BCMA system as it forced users through a linear and singular process in order to achieve administration of medication.

In an analysis of 2,783 errors reported to MEDMARX across 65 hospitals or health systems, Gary Cochran and his colleagues analyzed errors presented by and caused by BCMA systems. (Cochran, Jones, Brockman, Skinner, & Hicks, 2007) Nearly half of the errors identified were a result of mislabeled medicines or medicines missing a barcode. A related error was an inability to read the barcode as evidenced in the Koppel article above. In addition, there were issues where the system was not available and numerous workarounds documented in the database.

A smaller study conducted by Emily Patterson and her colleagues observed 33 nurses over an 81-hour period of time to analyze BCMA systems. (Patterson, 2002) They discovered usability problems with the interface, workarounds and failure of BCMA systems. They also identified coordination issues as a result of using the BCMA where it failed to highlight high priority medications and issues in communication between physicians and nurses resulting in coordination problems in patient care. A lack of flexibility in the system also caused problems where the system did not always match the workflow. In addition, the system often changed the workflow since there was a measure in place to monitor the administration of medications and whether they were administered on time. In many instances, nurses would rush to administer medicines so as not to be highlighted in the system as administering medications late. This became problematic when there were higher priority issues the nurses

should have been attending to, but were, instead, more worried about being monitored and reported on.

A body of work in HIT-induced errors that is, perhaps, the most complete representation is the work of Farah Magrabi and her colleagues. (Magrabi, Ong, Runciman, & Coiera, 2010, 2012) They have analyzed more than 500 different HIT-related errors in two different medical databases – the FDA's MAUDE database and Australia's AIMS incident reporting database. As a result, they have developed a categorical system of 36 different types of errors that stand as a framework for categorizing HIT-induced errors. Their system groups the 36 errors into five primary categories – Machine Input Problems, Machine Information Transfer Problems, Machine Output Problems, General Technical Problems and Human Contributing Factors as a Problem. This is a close representation of what this thesis attempts to produce. However, a shortcoming of this categorical schema is it does not adequately represent the sociotechnical factors involved in HIT-induced errors and adverse consequences. Nonetheless, this research is immensely valuable to the medical informatics profession as well as being a valuable resource to inform this study.

In addition to studies detailing the errors and adverse consequences of HIT, there have been a number of articles published in recent years from prominent voices in the medical informatics community calling for increased attention and efforts to HIT implementations, safety concerns and adverse effects of HIT. (Coiera et al., 2012; Karsh et al., 2010; Sittig & Singh, 2010, 2011) These are articles that propose new frameworks, summarize the effects of HIT or voice concerns over the current state of affairs with HIT in medicine.

A recent article from the Journal of the American Informatics Society (Karsh et al., 2010) provides an analysis of the adverse effects of HIT detailing what the authors consider to be nine HIT "fallacies." These fallacies illustrate potential and real problems stemming from the implementation of HIT. This article does not synthesize the research that has been completed in this area or present the types of the adverse effects of HIT in healthcare. Rather, the authors

are using what they term as HIT fallacies to call for increased regulation in the development and implementation of HIT.

Enrico Coiera details the state of affairs in healthcare and the plan for mass implementation for HIT in the future. (Coiera et al., 2012) He outlines the barriers and challenges that will occur in implementing HIT on a wide scale in the United States. In addition, he outlines the factors of HIT that increase harm and those that reduce harm calling for attention to these factors as HIT is developed and implemented.

Dean Sittig and Hardeep Singh have recently initiated work developing a framework for "understanding the complex origins of health information errors" and have worked to develop a sociotechnical model for measuring and understanding HIT-induced errors. (Sittig & Singh, 2009, 2010, 2011) In addition, they have sought to define an HIT-induced error as noted in the above section – Defining a Medical Error.

The research involving HIT-related errors spans more than a decade and is a testament to an increasing set of problems healthcare will face as it develops a closer relationship with HIT and a greater reliance. To date, there has been no major attempt to review the literature and compile the studies reporting on these adverse effects. Synthesizing the findings, coding and analyzing them will provide a lens through which to view implementations, developments and how healthcare will move forward in the decade to come.

Methodology

This study involved three primary stages. The first stage involved the location and selection of pertinent articles reporting HIT-induced errors. Once these articles were located and selected, the next stage involved coding the data. Validating the data represented the third stage of the study and as such, each stage receives due attention below. This section is split into three parts – The Literature Review, Coding the Studies and Validating the Coding.

Literature Review

The literature review for this study involved three primary stages – the initial literature search, a secondary search that built on the primary search and the selection of articles as a third stage. Selection of the articles to include the inclusion and exclusion criteria was an iterative process where the criteria were refined and defined over a series of stages.

A literature review was conducted between the months of May and July of 2012 to locate articles reporting on HIT-induced errors and adverse consequences of HIT. MEDLINE, CINAHL and Embase were searched using the key terms listed in Table 1. These databases were chosen for their broad coverage of the literature in the medical sciences. MEDLINE/Pubmed was chosen on the rationale it includes one of the broadest selections of journals in the medical field. CINHAL was chosen in an attempt to obtain studies within the nursing literature that may not have overlapped with the coverage of journals in MEDLINE. Embase was chosen due to it's focus on medicine and pharmacological literature and the relationship of this study to CPOE systems.

Table 1 Literature Search Key Terms

Health Information Technology	+	**Errors and Adverse Consequences**
• Clinical Pharmacy Information Systems • Hospital Information Systems • Decision Support Systems • Computerized Decision Support • Medical Records Systems, Computerized • Electronic Health Records • Computerized Medical Record • Medical Order Entry Systems • Automation • Information Systems		• Error • Medical Error • Medication Error • Unintended Consequences • E-iatrogenesis • Equipment Failure

A unique search strategy was employed where subject headings and keyword search were both used. Subject headings aided in locating those articles already indexed within the article database while keyword searching aided in

locating more recent articles that had not yet been indexed. In addition, the bibliographies of selected or pertinent articles were mined in an effort to locate related articles. Reverse citation searches were also completed using the Web of Science as a search tool. The reverse citation searches were completed on selected articles to locate additional pertinent sources. This strategy enabled a maximum return on the search garnering the greatest number of articles possible.

The inclusion and exclusion criteria were initially set broad to garner the greatest number of articles for review, as this was an obscure category unlikely to return massive results in the outset of the search. The initial criteria were:

1. The article must – as a primary focus – report on: CPOE, CDSS, or HIT. HIT will include technologies used to provide patient care. Examples would be Patient Information Systems, Medication Dispensing Cabinets, Bar Code Readers etc.
2. The article must also report on Errors, Unintended Consequences, Unanticipated Consequences, Adverse Events and/or Latent or Active Failures of HIT Systems.
3. Articles published from 1990 to 2012.

These initial criteria allowed maximum inclusion for the initial search and a refined set of criteria was developed and used after the initial search. This refined set of criteria was based on the findings and mass of articles located for the review. In addition, the revision of the search criteria came at the advice of a thesis committee member to enhance the sense of quality in the articles as well as develop a manageable number of studies for coding. The refined criteria were developed after the initial search and evaluation of articles. These criteria can be located in Tables 2 and 3. The criteria were strictly adhered to with the exception of a single paper by Joan Ash and colleagues, (2004) which used a Delphi style study design to reach a committee consensus on data. This paper offered a rich set of categories for Unintended Consequences as a result of HIT and was included

since it did include methods of data analysis consistent with qualitative data analysis.

Table 2: Exclusion Criteria

Exclude	Notes
Non-english	
Book Chapters, Conference Proceedings, Commentaries, Editorials, Preliminary Results	Exception Ash et al. (2004)
No Abstract	
Systematic Reviews, Reviews of the Literature and Integrated Reviews - these types of articles are primarily used to obtain original studies via bibliographic analysis	The exception to this rule is in rare cases where the synthesis of the literature results in a qualitative categorical schema that can be readily used for the current Integrated Review - or - a Systematic Review that adds new information to the topic
Does not report on specific errors or specific categories of errors - Lacks clarity or details about the errors to include the cause of the error or how it is a result of technology	Example: It does not help to know the physician chose the wrong drug 15 times using the CPOE. It only helps if we know they chose the wrong drug as the result of faulty arrangement in a drop down menu.
Is not complete in listing technology-induced errors	Example: Study that identifies 26 errors yet only provides 8 examples of the types or errors
Usability Studies / Simulations	Despite the usefulness of these studies, this research was meant to be based on real errors.

Table 3: Inclusion Criteria

Inclusion Criteria	Notes
Published 2002 - 2012	CPOE, BCMA and CDS have evolved significantly in the past decade. Articles older than 10 years truly represent early generations of these technologies and many were in stages of infancy.
Is a Peer Reviewed Journal	

Reports on Technology-Induced errors, adverse or unintended consequences of HIT or New Types of Errors introduced through HIT as sole focal point of article	There are a number of excluded articles addressing the benefits of the CPOE that list only a few "new types of errors" introduced as a result of the implementation. These articles are out of scope and insufficient in terms of the focus as they offer incomplete information and do not add to the study findings.
Empirical studies reporting actual, observed or recorded errors	Study was designed as an attempt to review potential errors, discrepancies, latent failures

Coding The Studies

The studies were coded using an iterative process to flesh out a schema that could be used to code all articles. A four-stage process was used to code the articles with each stage culminating in an evaluation of progress and validation.

The first stage began with an initial article to develop a rough set of categories and to validate a coding process. The article used in the first stage was Koppel's article studying CPOE. (Koppel et al., 2005) This article was chosen as an initial article at the suggestion of a thesis committee member and for its thorough coverage of errors in CPOE. The coding and categories were validated using the thesis committee for audting. The categories developed from this initial coding were used as a starting point and in coding future articles.

The second stage of the process involved coding two additional articles chosen for the diversity of their content in that they offered coverage of HIT-induced errors beyond CPOE and covered errors across healthcare system types. These two articles were coded with the Koppel article and to determine how well a coding schema would work using articles involving different types of HIT. The articles chosen were Emily Campbell and colleagues' article (Campbell et al., 2006) studying unintended consequences and Farah Magrabi and colleague's article studying patient safety issues from the AIMS database. (Magrabi et al., 2010) The three articles were coded using the set of categories initially developed through the Koppel article. When a category did not exist for an article, a new one was assigned. This allowed the categorical schema to be filled out as the coding process continued. At the conclusion of the second stage of coding, the studies and their resulting codes were validated with a member of the thesis committee.

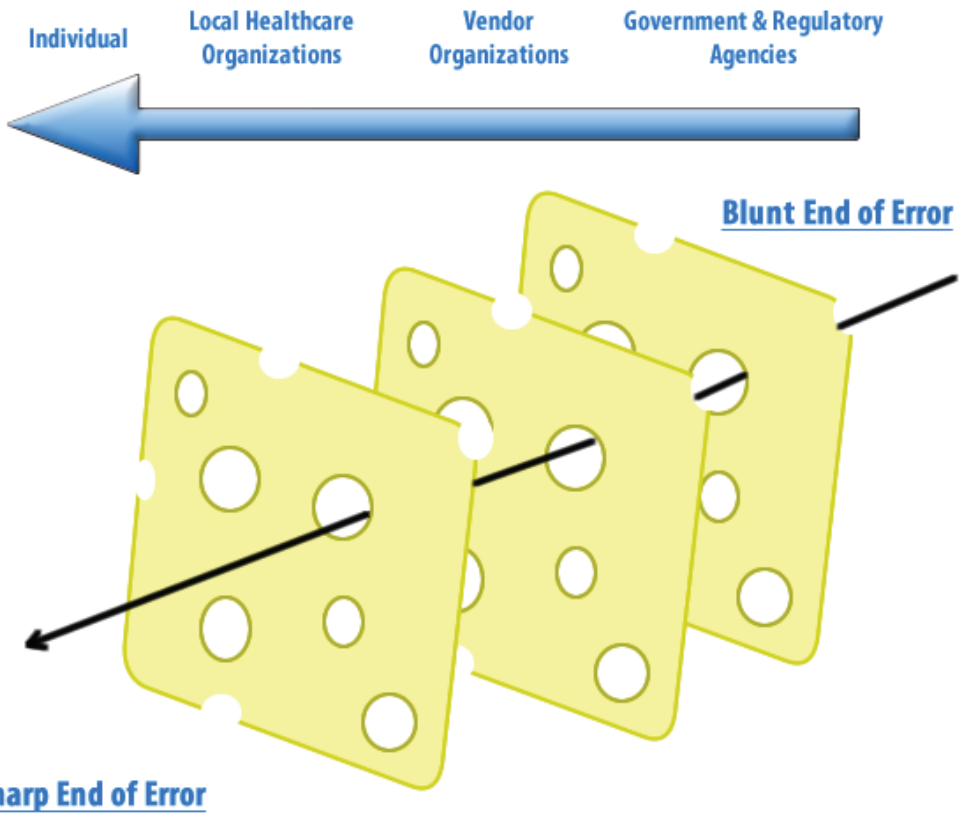
This initial categorical schema was supplemented with a framework developed by Elizabeth Borycki and colleagues, "A Framework for Diagnosing Technology Induced Errors in Healthcare." (Borycki, Kushniruk, Keay, & Kuo, 2009) Briefly, this framework is built on James Reason's Theory of Human Error and the Swiss Cheese Model of Human Error (Figure 1) where there is a sharp end (where the error occurs, usually performed by an individual) and a blunt end (where the error originates or where latent conditions exist and act in forming the

error). (Reason, 2000) In Reason's model, an error at the blunt end can occur as a result of organizational policies, software programming errors, design or any number of problems existing as a result of regulations or systemic problems in the beginning stages of development. At the blunt end, errors are not obvious. They are merely conditions predisposing an error at the blunt end. These problems are essentially "built into" the system and the conditions can then be carried throughout a system eventually resulting in a sharp end error. The sharp end is where the error actually occurs and usually involves a human. Additionally, systems are often modeled off existing systems or systems that are to be replaced with the newly programmed system. When these existing or older systems contain errors, it is common for errors in the old system to be modeled and built into the newer system. This framework was used as a guide in categorizing study errors. It is important to note: In many instances, studies do not offer a root cause analysis or a method to gain insight as to the root of an error. As such, this framework could only be used as a guide in categorization and is covered further in the discussion below.

The third stage of the coding process involved a selection of five articles for coding and validation, once again, against the framework described above and the coding developed as a result of using the framework. These articles were chosen from the total pool of articles selected for the study and were selected, once again, based on the diversity of their content and richness of data so as to provide a full representation of HIT-induced error categories. At the conclusion of this stage, the final studies were coded for a fourth stage.

In addition to coding the errors, the studies were also analyzed for the recommended actions to reduce the errors reported on, address adverse consequences of HIT or improve information systems in healthcare. These recommendations were compiled and trended to develop a cohesive set of recommendations for the reduction of HIT-induced errors and adverse consequences as well as recommended actions for future HIT development.

Figure 1: Swiss Cheese Model of Human Error



Validation

Qualitative data validation can be done through a variety of methods to enhance the rigor of the analysis and ensure solidity in the codification of data. (Patton, 1999) This study used two different methods of validation. The first method used a member of the thesis committee to oversee and audit the codification of study data. The second method utilized the authors of the studies to validate codification. This method has been cited in the literature and is an appropriate measure of validation given the nature and constraints of this thesis. (1999)

As noted above, the article coding was validated using an iterative process with the thesis committee in the first stage and one thesis committee member in the second and third stage of the coding. The fourth stage of coding used the second form of validation where the authors of studies were contacted to validate coding of errors from their studies.

Once all of the studies were coded, the authors of each study were contacted. Each author was given their data and a coding guide to inform them of the nature and details of the thesis. There were fourteen authors, total. Three authors could not be contacted due to faulty contact information, old contact information or they had moved on from research. Of the eleven remaining authors, ten agreed to review how their studies were coded and whether they agreed with the categorization. This comprised the final measure of validation for this thesis.

Results

Summary

The results section is divided into three parts. The literature search discusses the resulting number of articles located and the subsequent weeding process through the use of inclusion and exclusion criteria. The Classification of HIT-Induced Errors and Adverse Consequences section discusses the categorical schema developed and the resulting classification. The Prevalence and Impact of HIT-Induced Errors and Adverse Consequences section discusses the results of the coding with descriptive statistics to provide a summary of the impact and prevalence of problems found within the group of studies. Last, the Recommended Actions and Best Practices for Addressing HIT-Induced Errors and Adverse Consequences are presented.

Literature Search

The literature search resulted in 866 total articles available for review using the search terms described above. Of these, 55 were selected for manual review of abstracts and titles. Based on the inclusion and exclusion criteria, 45 of the articles were excluded leaving a total of 10 studies for review. The bibliographies of these 10 studies were then examined for pertinent articles garnering 3 additional articles. A reverse citation search was then employed on the 13 articles to net 5 additional articles for a total of 18 articles returned (n = 18) for evaluation and inclusion in the study. These 18 articles were then used as the

basis for the coding and categorization (Figure 2). Table 4 lists the articles selected for the integrated review.

Figure 2: Literature Search Results

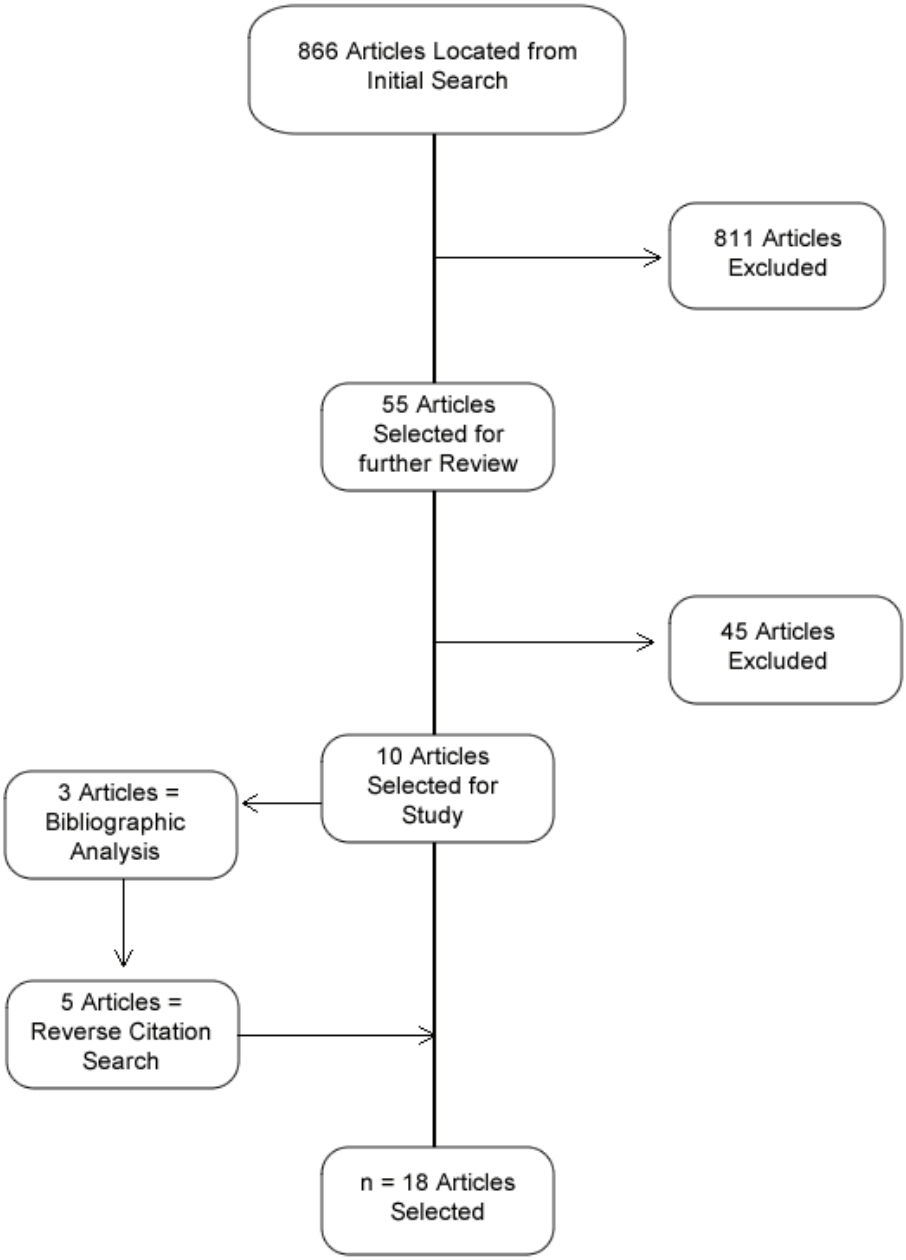


Table 4: Selected Studies for Integrated Review

Authors	System(s) Studied	Hospital(s) Profile	Methods / Data Sources
Ash, J. S., Berg, M., & Coiera, E. (2004). Some unintended consequences of information technology in health care: The nature of patient care information system-related errors. Journal of the American Medical Informatics Association : JAMIA, 11(2), 104-12.	Multiple Types - Multiple Data Sets	4 US Hospitals, Australian Hospital, Dutch 2 hospitals	Qualitative Analysis - Literature Review and Field Notes from Qualitative Research Conducted by the Authors, Quantitative Data from Dutch Hospitals
Ash JS, Sittig DF, Dykstra RH, Guappone K, Carpenter JD, and Seshadri V. Ash, J. S., Sittig, D. F., Dykstra, R. H., Guappone, K., Carpenter, J. D., & Seshadri, V. (2007). Categorizing the unintended sociotechnical consequences of computerized provider order entry. International Journal of Medical Informatics, 76 Suppl 1, S21-7.	CPOE	1 US Hospital, 4 outpatient clinics	Qualitative Analysis - Interviews and Ethnographic Observations
Campbell, E. M., Sittig, D. F., Ash, J. S., Guappone, K. P., & Dykstra, R. H. (2006). Types of unintended consequences related to computerized provider order entry. Journal of the American Medical Informatics Association : JAMIA, 13(5), 547-56.	CPOE	5 US Hospitals in 3 different organizations	Qualitative Analysis - Participant Observation, Semi-Structured Oral History Interviews and Transcriptions from a 2 Day Conference on Unintended and Adverse Consequences
Campbell, E. M., Guappone, K. P., Sittig, D. F., Dykstra, R. H., & Ash, J. S. (2009). Computerized provider order entry adoption: Implications for clinical workflow. Journal of General Internal Medicine, 24(1), 21-6.	CPOE	5 US Hospitals in 3 different organizations	Qualitative Analysis - Semi-Structured Oral History Interviews and Ethnography
Cochran, G. L., Jones, K. J., Brockman, J., Skinner, A., & Hicks, R. W. (2007). Errors prevented by and associated with bar-code medication administration systems. Joint Commission Journal on Quality and Patient Safety/Joint Commission Resources, 33(5), 293.	BCMA	65 US Hospitals / Health Systems	Qualitative Analysis - Error Reports from MEDMARX

Eslami S, Abu-Hanna A, de Keizer NF, and de Jonge E. Eslami, S., Abu-Hanna, A., de Keizer, N. F., & de Jonge, E. (2006). Errors associated with applying decision support by suggesting default doses for aminoglycosides. Drug Safety, 29(9), 803-809.	EMR - PDMS (Patient Data Management System)	1 Dutch Tertiary Care Hospital, Adult 28 bed ICU	Qualitative Analysis - Retrospective Evaluation of System Data
Han, Y. Y., Carcillo, J. A., Venkataraman, S. T., Clark, R. S. B., Watson, R. S., Nguyen, T. C., . . . Orr, R. A. (2005). Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system. Pediatrics, 116(6), 1506.	CPOE	1 US Children's Hospital 235 beds	Quantitative Analysis - mortality rate before and after implementation
Horsky, J., Kuperman, G. J., & Patel, V. L. (2005). Comprehensive analysis of a medication dosing error related to CPOE. Journal of the American Medical Informatics Association, 12(4), 377-382.	CPOE	1 US Hospital, ICU	Qualitative Analysis - Case Study (log analysis, interviews and heuristic evaluation of CPOE interface)
Koppel, R., Metlay, J. P., Cohen, A., Abaluck, B., Localio, A. R., Kimmel, S. E., & Strom, B. L. (2005). Role of computerized physician order entry systems in facilitating medication errors. JAMA : The Journal of the American Medical Association, 293(10), 1197.	CPOE	1 US Teaching Hospital 750 beds	Qualitative Analysis - One-on-One Interviews, Focus Groups, Expert Interview, Shadowing, Survey
Koppel, R., Wetterneck, T., Telles, J. L., & Karsh, B. T. (2008). Workarounds to barcode medication administration systems: Their occurrences, causes, and threats to patient safety. Journal of the American Medical Informatics Association : JAMIA, 15(4), 408-23.	BCMA	1 US Hospital (470 bed), 4 Hospital Healthcare System (929 bed)	Qualitative Analysis - Structure Observations & Shadowing, Unstructured & Semi-structured Interviews, Participation in Hospital Staff Meetings about BCMA, Data Log Review, Failure Mode & Effects Analysis (FMEA)
Magrabi, F., Ong, M. S., Runciman, W., & Coiera, E. (2010). An analysis of computer-related patient safety incidents to inform the development of a classification. Journal of the American Medical Informatics Association : JAMIA, 17(6), 663-70.	Multiple Types - AIMS Data	8 Australian Hospitals	Qualitative Analysis - Patient Safety Incidents Reported via AIMS

Magrabi, F., Ong, M. S., Runciman, W., & Coiera, E. (2012). Using FDA reports to inform a classification for health information technology safety problems. Journal of the American Medical Informatics Association : JAMIA, 19(1), 45-53.	Multiple Types - FDA Data	Multiple	Qualitative Analysis - 1100 reports via MAUDE Database
McDonald CJ. McDonald, C. J. (2006). Computerization can create safety hazards: A bar-coding near miss. Annals of Internal Medicine, 144(7), 510-6.	BCMA	1 US Hospital	Case Study
Niazkhani, Z., Pirnejad, H., van der Sijs, H., & Aarts, J. (2011). Evaluating the medication process in the context of CPOE use: The significance of working around the system. International Journal of Medical Informatics, 80(7), 490-506.	CPOE	1 Netherlands Academic Hospital (1237 beds)	Qualitative Analysis - Transcripts of Interviews with End-users, Document Analysis, Educational/Training Material Analysis
Patterson, . S. (2002). Improving patient safety by identifying side effects from introducing bar coding in medication administration. Journal of the American Medical Informatics Association, 9(5), 540-553.	BCMA	VA - Acute Care and Nursing Home Wards, 3 Hospitals	Qualitative Analysis - Ethnographic Observation Before and After BCMA Implementation
Santell, J. P., Kowiatek, J. G., Weber, R. J., Hicks, R. W., & Sirio, C. A. (2009). Medication errors resulting from computer entry by nonprescribers. American Journal of Health-system Pharmacy : AJHP : Official Journal of the American Society of Health-System Pharmacists, 66(9), 843-53.	CPOE	Multiple – 693 Unique Facilities	Quantitative Analysis - MEDMARX Records
Walsh, K. E., Adams, W. G., Bauchner, H., Vinci, R. J., Chessare, J. B., Cooper, M. R., . . . Landrigan, C. P. (2006). Medication errors related to computerized order entry for children. Pediatrics, 118(5), 1872-9.	CPOE	1 US 40-bed Teaching Hospital	Quantitative Analysis - 352 Randomly selected inpatient pediatric admissions retrospectively reviewed 3 to 12 months after implementation
Wetterneck, T. B., Walker, J. M., Blosky, M. A., Cartmill, R. S., Hoonakker, P., Johnson, M. A., . . . Carayon, P. (2011). Factors contributing to an increase in duplicate medication order errors after CPOE implementation. Journal of the American Medical Informatics Association : JAMIA, 18(6), 774-82.	CPOE	1 US Teaching Hospital 400-bed	Qualitative Analysis - 4147 patient days prior to implementation and 4013 patient days after implementation

Classification of HIT-Induced Errors and Adverse Consequences

The articles netted 228 points of data coded. As noted above, the codes were developed iteratively with each error being coded into an initial set of 11 master categories. The 11 master categories were developed using categories within the articles used for coding and developing the extracted errors into themes through the coding process. These themes were trended and error categories were developed using the trended themes. Errors that did not fit into existing categories were placed in a miscellaneous category to be analyzed for trends within the entire set of errors. These trends were then assigned a category based on the representation of errors as they were described in the article. In most instances, an article would provide a category for an error that was acceptable or common terminology was extracted from the article and later trended through the categorization process. In few instances, categories were difficult to distinguish. An example would be the category for Social Informatics. This is a difficult category to assign because of the ambiguous nature of the issues contained within that particular category. This process was employed over three stages with a four stage implemented for the development of the taxonomy. The trended categories were subsequently audited by a thesis committee member for accuracy in representation.

The master categories (Table 5) were used as initial codes to label the errors in each article. The number of errors per category can be found in Table 6 and the percentage distribution can be viewed in Table 7. Figures 3 – 5 provide graphical representations of the distributions. The 11 master categories served as a framework and guide for the entire coding process and, as such, warrant further description.

Automation bias represented 7 percent of the problems associated with HIT in the articles and was located in 39 percent of the studies. In most cases, it refers to an over-reliance on technology or the assumption that technology is not to be questioned. (Campbell et al., 2006) However, this category also refers to changes occurring in communication patterns as a result of technology. For example, placing an order into the CPOE system does not ensure the order will be

seen or acted upon. Another example of automation bias would be the reliance on printers printing off orders to be acted upon or printers that act as notifications affecting the workflow. In many instances, the printer jams, runs out of paper or ceases working for some other reason halting the workflow. An over-reliance on technology has also been shown to influence physicians' decisions adversely when using CDS. (Campbell et al., 2007; Goddard, Roudsari, & Wyatt, 2011a, 2011b, 2012)

Cognitive Overload represented only 4 percent of all errors identified, but was identified in 17 percent of the studies analyzed. Cognitive overload refers to simply having more tasks than one can complete or more information than needed for the primary task at hand. (Ash et al., 2004) An example would be a system that overloads the user with too much information – most of which is not pertinent to the task needing to be completed. Cognitive overload was a category used to label errors related to distraction or interruption as well. In addition, it represents those instances of when a user made a critical omission (omission error) or failed to log off of a system. Alert fatigue – while also a Programming / IT issue – can be cross-listed in this category as well.

Table 5: Master Categories

Master Categories	Description
Automation Bias	Overreliance or dependence on HIT - this includes human assumptions about the abilities of computers in addition to communication issues (i.e. assuming a message sent is a message read)
Cognitive Overload	Includes interruption or distractions and refers to any errors caused as a result of too much information or too many tasks at a given time
Integration of Systems	Problems associated with the integration of systems or lack thereof. When systems are improperly integrated this often leads to a mismatch in information where results are skewed, images are oriented incorrectly, system behavior is not as it was programmed.
Interface Design / HCI	Any issue associated with the GUI causing an error - this should also include information design and representation
Programming / IT	Issues related to faults in the programming of the system, testing of the system, rules in the system not being set properly, including issues where the system reports incorrect values or misrepresents medical information.
Rigidity of Systems	When systems force users to a certain pathway or will not allow variance in a routine. This differs from workflow issues where the system simply is mismatched with the workflow causing extra effort or time to be spent on tasks.
Social Informatics	Issues involving the interaction of humans and information technology resulting in negative emotions, power restructuring, reorganizing etc.
System Availability	System malfunction (not due to programming error), system outage, system downtime, errors caused in updating
Training / Support	IT support and appropriate education / tools in using systems
Workaround	Any deviation from defined process (usually resulting from a workflow issue or a routine that is especially time consuming or does not respect the workflow of a complex environment).
Workflow	System design does not reflect or respect the workflow causing time constraints, errors, or workarounds in some instances

Integration of Systems represented only 5.7 percent of all errors, but was identified in a third of all articles. System integration essentially refers to hospital systems that do not communicate or, in some instances, communicate inappropriately with one another and cause errors. In an example from one article, systems would mismatch data and send erroneous data to another system resulting in the wrong patient or wrong images being displayed on screen. (Magrabi et al., 2010) Integration of systems, in this particular article, resulted in patient deaths. Most problems were not as serious as this and related to issues such as nursing systems not communicating with physicians' systems or a user having to enter information from one system into another manually as a result of disconnected systems. A large percentage of this problem relates to the use of appropriate languages for system communication such as HL7 and LOINC for laboratory data. Using controlled vocabularies and the appropriate terminological sets also constitutes a major recommendation for the improvement of future HIT systems discussed below.

Interface Design / HCI made up the bulk of the errors and adverse consequences found representing nearly a quarter of all coded items and found in 89 percent of all studies. The types of problems identified as a result of interface design were broad and represented issues such as juxtaposition errors in selecting from dropdown menus, inability to find items within a system, lack of cohesion in design and the presentation of data. It is important to note some issues with interface design are difficult to analyze and determine whether they are design issues or programming issues. For example, fragmented system screens often force the user to click through multiple screens in order to gain a complete understanding of a given patient's historical record and often induce error. Though this is clearly an interface related issue, it is not always clear if this is the result of the way the system was programmed or the manner in which it was designed as an interface. In addition, this is an issue where the poor design of the interface causes cognitive overload and thus there exists some permeability between categories. This is discussed below.

Programming / IT issues related to 13.6 percent of problems identified, but these issues were found in 78 percent of all studies analyzed. Programming and IT issues referred to system malfunctions, incorrect algorithms in figuring dosages or a metrics for patient care, incorrect (or missing) safety parameters and erroneous automation settings where the system either automated something it should not have or did not automate something it should have. These problems were extremely prevalent in the studies and comprise a large portion of problems in HIT. Reliability is a serious issue with HIT and putting systems in place with no plans for outages or backups posed significant problems and serves as a primary recommendation for HIT improvement from a number of researchers in the field. (Coiera et al., 2012; Magrabi et al., 2010, 2012; Sittig & Singh, 2009) It also was an issue attributed to numerous errors across the studies.

Rigidity of Systems only accounted for 7 percent of all errors, but was identified in half of the studies analyzed. This concept refers to how flexible or "forgiving" a system is in respect to the workflow. It is not a problem with workflow as described below, but rather a problem with guidelines enforcement, policy enforcement, lack of allowance for process deviation or support of multiple tasks or users. Rigidity of Systems can best be described as the system forcing or dictating users' actions and can be considered a subset of programming issues in some, but not all, cases.

Social Informatics was a small subject category at 3 percent and refers to the interaction of humans with a system or technology and its social affects to include the emotional impact a system may cause, changing a power structure or other behavioral issues resulting from the use or the implementation of technology. An example is the restructuring that often occurs as a result of IT implementation and how IT can change the power structure in a given organization or department. In many instances, nurses who gain mastery of the system gain a greater sense of import in a department. This also occurs with IT professionals who possess specialized knowledge of a system. (Ash et al., 2006)

System Availability represented 11.8 percent of all identified issues, but was a problem in half of all studies analyzed. Systems often cease working or

develop operational problems taking them "off line." When this occurs, the system is not available or may be unresponsive. This category included items such as device failure in the case of BCMA technology, system upgrades that took the technology offline and, in some cases, this referred to the physical location of systems. System availability was especially a problem in one case where systems were not located at bedside. (Niazkhani, Pirnejad, Berg, & Aarts, 2009) This forced physicians and nurses to remember orders until they could gain access to a system. In some instances, physicians would have to wait until they returned to an office. Availability of systems can also become a problem when not enough terminals are available in a given department.

Training and Support only represented 3.5 percent of all identified HIT problems, but was identified in 28 percent of all studies underscoring the importance of training on new (and even older) systems. When the implementation of systems is considered, training and support have been found to be of the utmost importance. (Ash, Stavri, & Kuperman, 2003) Users, in many instances, did not understand basic aspects of the system such as ordering procedures, which caused errors. In some instances, users did not understand organizational policies in regards to using the system. In the use of BCMA technology, one study cited users did not understand the safety benefits offered through the use of such systems or the importance of using such systems. (Koppel et al., 2008) Other issues included ergonomics and computer carts not being well designed for use in rooms or to hold charting material for transcription.

Workarounds represented 4.8 percent of all categories and were located in a third of the studies analyzed. Many of the issues involving workarounds revolve around systems being poorly designed or systems that create more/new work for the end-user. (Campbell et al., 2006) There were generally two types of workarounds – those involving the system and those representing both physical and system constraints. Issues involving the system only refer to problems where the user would work around the system as a result of the system. An example is using excessive cut and paste within the system or finding shortcuts within the system that increase the likelihood of error or cause adverse consequences. An

example of a physical constraint causing a workaround is in one system, nurses would borrow medicines from other units' medicine cabinets and replace them later because the CPOE ordering system often took too long to get medicines to the floor. Paper persistence was also an issue involving physical artifacts used as a workaround where professionals would sometimes keep items on paper and enter them in the system later or make changes in a paper chart that were not placed into the system causing inconsistencies in the record of care.

Workflow problems represented 12.7 percent of all issues identified and 56 percent of the studies analyzed. The most common problem seen within workflow is when the system does not actually match the physical workflow. Examples of this include patient location in the hospital either allowing duplicate orders (because the patient is able to be accessed in more than one location) or the wrong patient being cued into the system as a result of a location mismatch. Often, the paper process does not match the system leading to gaps between what is seen in the system versus the care documented on paper. The largest number of workflow related issues involved how the implementation of the system would change the workflow. One example involved a system that could monitor when medications were administered and report when medications were administered late. This problem is described above in the Background and Literature Review section. This was an issue that not only changed workflow (because nurses would often delay items that clearly had a higher priority so as not to be reported in the system as administering medicine late), but it also can be (and was) categorized as a sociotechnical issue due to the anxiety it caused among nurses. In addition, there were delays in workflow as a result of systems use. For example, an order might not be in the system yet meaning it cannot be acted upon or medication may have been ordered but nurses must wait on the physical arrival, which is slower with the new system. Interestingly, there were changes in communication patterns that affected workflow. But these same issues are also sociotechnical in that the technology has an effect on the social aspects of the work environment.

These results provide an overview of the types of errors and the prevalence of these errors in the studies analyzed. These initial master categories

are not exclusive and in many instances, one error can have more than a single cause. This is discussed in the Discussion Section below. However, defining and identifying major categories of errors found in the literature provides an enhanced mental model of the problems facing future HIT use and implementations in the United States.

Table 6: Distribution of 11 Master Categories

Master Categories	Number of Errors (n=228)	Percentage of Errors
Automation Bias	15	6.6
Cognitive Overload	9	4.0
Integration of Systems	13	5.7
Interface Design / HCI	52	22.8
Programming / IT	31	13.6
Rigidity of Systems	16	7.0
Social Informatics	7	3.0
System Availability	27	11.8
Training / Support	8	3.5
Workaround	11	4.8
Workflow	29	12.7

Table 7: Percentage Distribution of 11 Master Categories

Master Categories	Number of Studies (n=18)	Percentage of Studies
Automation Bias	7	39
Cognitive Overload	3	17
Integration of Systems	6	33
Interface Design / HCI	16	89
Programming / IT	14	78
Rigidity of Systems	9	50
Social Informatics	3	17
System Availability	9	50
Training / Support	5	28
Workaround	6	33
Workflow	10	56

Figure 3: Number of Errors Per Category

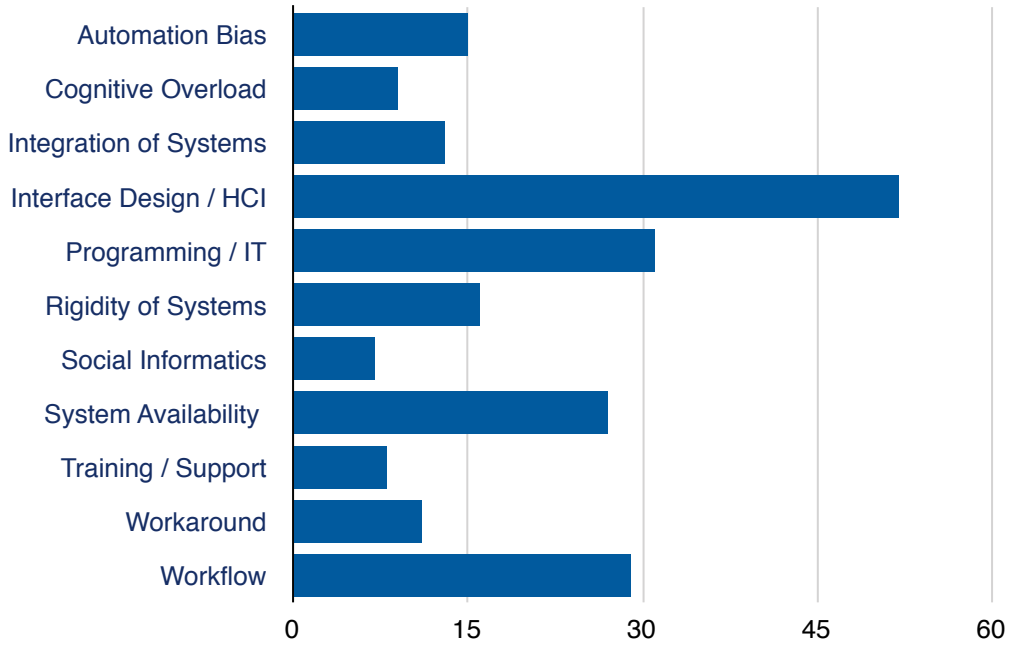


Figure 4: Percentage of Errors per Category

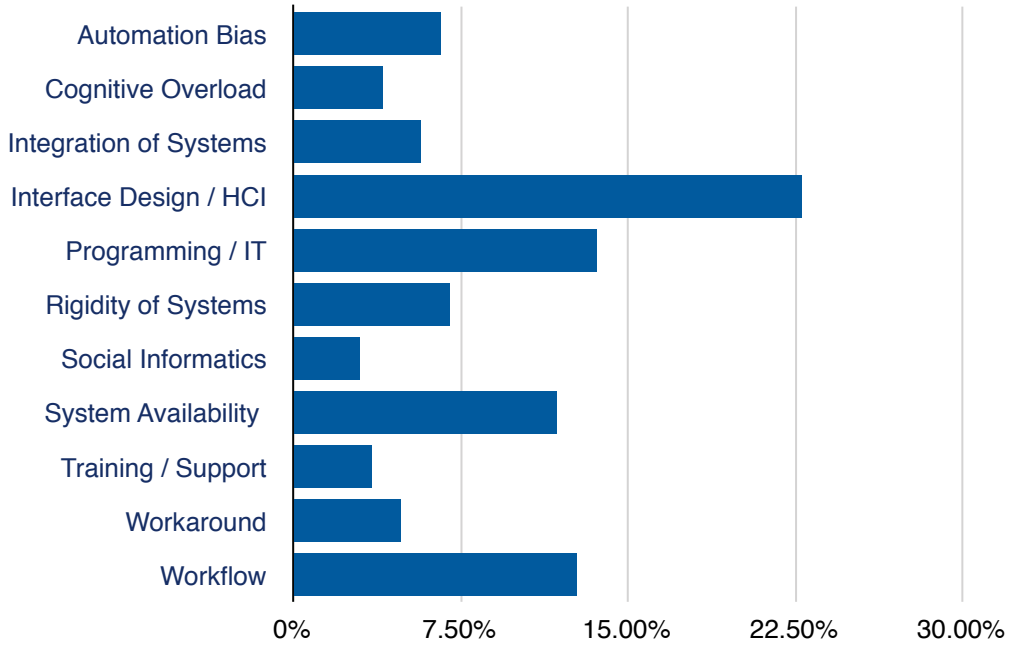
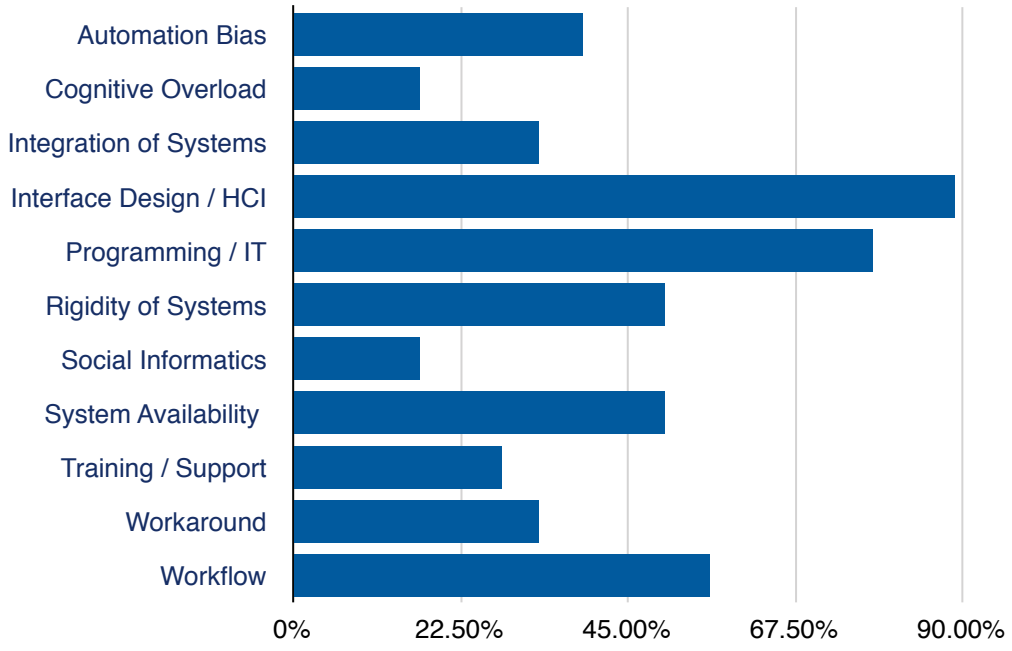


Figure 5: Category Percentage Per Study



The eleven master categories, representing 228 identified errors, were then grouped and used to develop a taxonomic representation of errors – a classification schema more precisely representing the overall nature of different errors identified. Each of the 11 master categories was evaluated as a sole category to identify error trends within the individual category. These trends were then placed with each of their respective categories and the 11 master categories were then evaluated in a final review to develop a holistic framework for the taxonomic representation. Thirty subcategories were identified based on the error trends within each of the original 11 master categories. This allowed for a more precise schema in terms of a classification system. In three instances, a "master category" was grouped into a larger overarching category that more precisely represented and described the range of errors found within that category. This occurred with three of the eleven master categories. Automation Bias and Cognitive Overload were grouped into an overarching category titled the Negative Effects of Augmentation because they both represent problems in automation or augmentation through the use of technology. Integration of Systems was grouped

under the category System Availability primarily because the lack of systems integration represents a gap in the availability of a given system from another system. The taxonomic representation can be viewed in Table 8 with respective descriptions for the 30 subcategories.

The taxonomic representation provides a more granular view in the sense that it provides a division within differing categories. It also provides a greater specificity that enables a better understanding of what errors are representing within the master categories. This taxonomic representation could be utilized not only to provide an understanding and overall picture of HIT-induced errors in healthcare, but could also serve as a modeling framework for future categorization or research in this area of study.

Table 8: Classification of HIT-Induced Errors

Classification	Description / Examples
1.0 Interface Design / HCI	
1.1 Devices	Problems in using devices, interpreting beeps (BCMA), Ergonomic issues in using devices such as carts, computer terminals or work areas.
1.2 Feedback	Alerts poorly designed, unclear system procedures, unclear update procedures, Alert override, Automation surprise
1.3 Information Design	Data presentation confusing, Paper labels poorly designed, High priority items not accentuated or highlighted
1.4 Lists	Ordering of lists confusing, Juxtaposition Errors, Cannot reorder list
1.5 Navigation	Search interface lacking, Unclear log-off, Labeling confusing
1.6 System Burdensome	Too many steps, Too many clicks, Confusing interface
2.0 Negative Effects of Augmentation	
2.1 Automation Bias	Assuming the system is correct (CDS), Assuming an order placed is an order carried out
2.2 Brain Plasticity	Forgetting previous manual processes (i.e. How to do things the old way)

2.3 Cognitive Overload	Interruption, Distraction, Too much information
2.4 Overuse of Automation	Excessive copy and paste, Changing clinical orders to standardized (and meaningless) phraseology
3.0 Programming / IT	
3.1 Erroneous Automation Settings	Orders do not cancel (leading to duplicate orders), Medications not discontinued by default
3.2 Incorrect Algorithms / Calculations	Dosing algorithms wrong, Dosing measurements incorrectly rounded up, Dosing measurements wrong
3.3 Incorrect Safety Parameters	No time out for log-out, Patients can be accessed in more than one location, System does not contain contraindication data
3.4 System Malfunction	Interface displays wrong information, BCMA does not detect wrong patient, Incorrect alerts
4.0 Rigidity of Systems	
4.1 Data Entry / Guideline Enforcement	Policies and Guidelines force users to enter supplementary information, Forcing order justification
4.2 Process Deviation	Cannot deviate from set process in system, Orders cannot be placed until patient registered in system, ER situations do not allow flexibility
4.3 User Management	Support for multiple users, Patient transfer problems when attached to physician and new physician cannot enter orders for patient
5.0 Sociotechnical Issues	
5.1 Emotional Impact	Feelings of resentment or frustration for system problems
5.2 Change in Power Structure	IT or professionals with above average technical abilities gain power over other workers
5.3 Changes in Communication Patterns	System eliminates much face-to-face interaction.
6.0 System Availability	

6.1 Device Failure	BCMA batteries dead, BCMA failure, BCMA not scanning
6.2 System Down / Offline	System upgrades, Complete system failure, System down or offline
6.3 System Integration	LIS (or other systems) not integrated with EMR
6.4 System Location	System not easily accessible due to location of terminal or location of EMR access
6.5 System Speed	System too slow or delayed or freezing screen
7.0 Workarounds	
7.1 Physical Constraints	Paper persistence
7.2 System Constraints	Not using BCMA, Charting after shift
8.0 Workflow	
8.1 Mismatched Workflow	System does not parallel workflow leading to wrong patient, wrong meds or patient location problems
8.2 Paper to System Mismatch	New system leaves some users out of process and thus removes checks and balances in old paper-based system, Paper-based system had a method of alerting for X and new system does not
8.3 System Changes Workflow	System forces change in workflow as a result of linear processes

Prevalence and Impact of HIT-Induced Errors

Introduction

Measuring the prevalence and impact of HIT-induced errors can be difficult for a number of reasons. First and foremost, it is extremely difficult to gage the prevalence or impact of HIT-induced errors beyond this study. In addition, the majority of the studies analyzed for this review involved qualitative data collection and analysis – the very nature of which made it impossible to determine error rates in an accurate manner. There are two primary means to determine, on some level, how prevalent these types of errors are and how concerned the healthcare profession should be about HIT-induced errors, adverse

consequences of HIT and safety issues involving information technologies in healthcare. The first means is to evaluate the representation of studies from the literature review completed for this study. The second means is to evaluate recent events and publications surrounding these issues.

Prevalence and Impact Within the Study

Given the rigor of the literature review, it is possible to represent the distribution of studies across varying health information technologies and illustrate the gaps in the literature. Table 9 provides an overview of the technologies covered with the studies analyzed to include the percentile of each technology within the 18 studies analyzed. This section covers the technologies represented within the study – CPOE, CDS, BCMA and studies examining multiple systems in a single study.

Table 9: Representation of HIT in Studies

HIT System	CPOE	CDS	BCMA	Multiple*
Number of Studies	11	2	4	3
Percentage of Studies	61%	11%	22%	16.7%

*The "Multiple Category" denotes data pulls from patient safety systems or reporting databases such as FDA, MEDMARX, AIMS.

Clinical Decision Support Systems

CDS is an underrepresented topic. This is most likely due to the nature of CDS in that most studies analyzing the effects of CDS examine automation bias in relation to how the system can influence the decisions of healthcare professionals. A large majority of studies located via the literature search examining CDS were conducted in test environments and were thus excluded from this study. Most often, the tests were conducted as part of a usability analysis or a simulation. The 2 studies included in this review evaluating CDS were part of a CPOE system evaluation and thus are pulled out from the original 18 studies evaluated so there is an accurate representation of CDS as a technology represented in the studies.

Bar Code Medication Administration Technologies

BCMA is a relatively underrepresented topic in the literature as well. Of the four studies analyzing BCMA, one was a case study offering a singular incident. One was a study using a MEDMARX dataset (Cochran et al., 2007) evaluating 2,783 error reports and representing the largest dataset for the BCMA studies analyzed. However, large datasets from databases do not always offer the depth of explanation one might obtain through qualitative research methods such as ethnography, interviews and observation. By far, the most rigorous study conducted was by Ross Koppel and his colleagues. (Koppel et al., 2008) This study evaluated BCMA in the context of workarounds (the most common problem with BCMA technology along with failure of the device) using qualitative methods of data gathering and log review, which is arguably quantitative in nature. There were a number of viewpoint pieces, editorial spots and commentaries available on BCMA, but the number of high quality studies located for this thesis was low.

Multiple Technologies Studied

There were three studies that examined errors and patient safety incidents across a number of technologies. (Ash et al., 2004; Magrabi et al., 2010, 2012) Two of these studies analyzed a large data set pulled from the FDA and another pulled from AIMS patient safety incident reporting database in Australia. (Magrabi et al., 2010, 2012) In all, these two studies evaluated 559 adverse events reported in AIMS and MAUDE and included a broad range of technologies to include Patient Information Systems, BCMA, EMR and CPOE. In addition, these two datasets represent an international crosscut of data and a cross-section of HIT-induced errors by technology. Joan Ash and colleagues also conducted a study at an international level gathering qualitative and quantitative data from US hospitals, Australia and the Netherlands. This was a rich dataset used to examine the unintended consequences of Patient Care Information Systems (PCIS) and related errors.

Table 10: Distribution of Errors Per Study

	Ash 2004	Ash 2007	Campbell 2006	Campbell 2009	Cochran 2007	Eslami 2006	Han 2005	Horsky 2005	Koppel 2005	Koppel 2008	Magrabi 2010	Magrabi 2012	McDonald 2006	Niazkhani 2011	Patterson 2002	Santell 2009	Walsh 2006	Wetterneck 2011
Automation Bias	X		X			X			X	X			X				X	
Cognitive Overload											X					X	X	
Integration of Systems			X	X					X		X	X						
Interface Design	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X	
Programming / IT	X	X	X	X				X	X		X	X		X	X	X		X
Rigidity of Systems	X		X	X			X			X		X					X	X
Social Informatics		X	X				X											X
System Availability			X		X		X		X	X	X	X			X			
Training / Support		X						X		X	X					X		
Workaround	X		X		X				X					X	X			
Workflow	X	X	X	X	X		X		X	X		X		X	X			X

Computerized-Provider Order Entry

CPOE, by far, represented the largest amount of the literature located for HIT-induced errors and adverse consequences. The majority of the studies excluded, often reported on a small subset of errors in the use of CPOE and there are a number of reviews on CPOE that included a section concerning errors as well. These studies did not meet exclusion criteria in most instances because they did not provide adequate explanations for the errors, represented an incomplete accounting of errors or simply did not meet inclusion criteria in other ways. The CPOE literature, however, is robust in terms of reporting on the errors associated with this technology. And, once again, Ross Koppel and colleagues' work in this field represent a very good foundation. (Koppel et al., 2005)

The Prevalence and Impact of HIT-Induced Errors in the Literature

There are a numerous authoritative organizations and medical research scientists currently voicing concern over the errors occurring in relation to technologies in healthcare. The literature is rife with such examples from organizations such as the Institutes for Medicine (IOM), The Joint Commission and The Institute for Healthcare Improvement (IHI).

IOM has published two books on the errors in healthcare and associated problems with technology. (*Crossing the Quality Chasm :a New Health System for the 21st Century,* 2001; Kohn et al., 2000) But, a more recent report focuses specifically on HIT-induced errors and makes recommendations for safe implementation and use of HIT. (Safety et al., 2012) In this report, the IOM states:

> "The portfolio of research on health IT has included little regarding the general impact of health IT on safety of clinical care. The evidence in the literature about the impact of health IT on patient safety is mixed but shows that the challenges facing safer healthcare and safer use of health IT involve the people and clinical implementation as much as the technology."

The Joint Commission, however, cites statistics on the matter and has recently published two major reports regarding the safety of health IT. (Commission, 2009; The Joint Commision, 2009) In one report, they also note a scarcity of data on the subject and state:

> "The United States Pharmacopeia MEDMARX database includes 176,409 medication error records for 2006, of which 1.25 percent resulted in harm. Of those medication error records, 43,372, or approximately 25 percent, involved some aspect of computer technology as at least one cause of the error. Most of the harmful technology-related errors involved mislabeled barcodes on medications (5 percent), information management systems (2 percent), and unclear or confusing computer screen displays (1.5 percent). The remaining harmful errors were related to dispensing devices, computer software, failure to scan barcodes, computer entry (other than CPOE), CPOE, and overrides of barcode warnings." (Commission, 2009)

Though a dearth of data and statistics exist on HIT-induced errors and adverse consequences in healthcare, these major reports from authoritative bodies in the industry suggest there is, at the very least, significant concern over widespread implementation of IT in healthcare over the next decade. The IOM has formed a committee (or task force) on the subject to make recommendations for safer use and implementation of HIT. (Safety et al., 2012)

In recent literature, there have been voices of prominent researchers in the medical field exploring a number of related issues to HIT-induced errors and HIT implementations. Dean Sittig and Hardeep Singh have recently authored a paper in which they provide insight to defining HIT-induced errors and a framework for deployment and implementation of HIT. (Sittig & Singh, 2011) In addition, they have also authored a publication detailing eight major principles in safe electronic health record use. (2009) Enrico Coiera and his colleagues have also authored a commentary paper in which they address issues and problems in HIT and the rocky road ahead as a nation strives to bring healthcare technologies into the new

millennium. (Coiera et al., 2012) Ben-Tzion Karsh has published a viewpoint paper that not only underscores the problems in HIT, but also seeks to correct the fallacies associated with HIT such as the idea that no risk exists or that humans can be to blame for HIT-induced errors and adverse consequences. (Karsh et al., 2010) This paper also explores an emerging idea in proposing EMR, CPOE, CDS and BCMA technologies should be brought under the regulation of the Food and Drug Administration.

If the trends in the literature and governing bodies are any indication of importance in relation to HIT-induced errors, it appears it is of significant concern and importance. Yet, there remain little quantitative measures to assess how prevalent or how pervasive HIT-induced errors are in medicine or how great the impact. We can – at this point – merely speculate that Meaningful Use and the HITECH act will spawn widespread implementation and adoption of technologies that may or may not result in significantly greater harm than what is currently cited in the medical literature. At best, we can only hope the current research surrounding HIT-induced errors will provide a portal with which to view what could exponentially become problematic in healthcare systems and facilities across the country.

Recommended Actions and Best Practices in Addressing HIT-Induced Errors

All 18 studies were analyzed for recommendations and any recommendations were then compiled and trended in the final analysis of each study (Table 11). Of the 18 studies, 3 provided no recommendations or best practices to follow. Of the remaining 15 articles, a total of 84 recommendations were identified, compiled and analyzed for trends. Seventeen recommendations were identified across the studies – not all of which concurred with other studies (or trended). But all recommendations were represented.

Improving the interface design was the single greatest recommendation and was made across 8 of the studies. (Ash et al., 2004; Campbell et al., 2006; Cochran et al., 2007; Horsky, Kuperman, & Patel, 2005; Magrabi et al., 2010, 2012; Patterson, 2002; Wetterneck et al., 2011) This included problems with

labeling where it could possibly confuse users such as mg versus g or IV versus IP and writing these values out instead of using abbreviations, (Cochran et al., 2007; Horsky et al., 2005; Magrabi et al., 2010) systems interfaces that can remind users what they were last doing if interrupted, (Ash et al., 2004) and system interfaces that do not force users to move across several screens to obtain a historical account of a patient situation. (Magrabi et al., 2012; Patterson, 2002) Another recommendation was to highlight high-risk medications within the system interface. (Wetterneck et al., 2011) Alerts were also targeted by several studies asking for improvement of alerts design and activation so as to reduce alert fatigue and avoid excessive alert overrides. (Ash et al., 2004; Cochran et al., 2007; Horsky et al., 2005; Walsh et al., 2006)

Greater attention to training and educating the end-user was recommended. (Ash et al., 2004; Cochran et al., 2007; Horsky et al., 2005; Magrabi et al., 2010; Patterson, 2002; Santell et al., 2009) This included training the end-user in safety features of the system, spending more time on training and special attention to training during new installations or significant upgrades. One study called for increased investigation of workarounds involving the use of BCMA systems and subsequently training users on the appropriate procedures. (Cochran et al., 2007) It is important to note while training and education are important parts of an implementation of HIT, they in no way substitute or replace solid system design. Workarounds are often a symptom of poor system design and users cannot and should not simply be trained to manage poor design.

There was a significant call for standards or the application of standards in interface design efforts or standards in system development for HIT. (Campbell et al., 2009; Han et al., 2005; Koppel et al., 2008; Magrabi et al., 2010, 2012; Wetterneck et al., 2011) More research into the use of HIT, behavior surrounding the use of HIT and the employment of workarounds was also a major recommendation. (Ash et al., 2004; Campbell et al., 2009; Cochran et al., 2007; Eslami, Abu-Hanna, de Keizer, & de Jonge, 2006; Koppel, 2005; Koppel et al., 2008) Improvements in CDS to include a call for more robust CDS, using patient-specific information to advise physicians of guidelines and better medication

decision support were recommendations as well. (Eslami et al., 2006; Santell et al., 2009; Walsh et al., 2006; Wetterneck et al., 2011)

Less frequent recommendations included greater attention to developing systems that compliment workflow, improving integration of systems, involving end-users in the design process (participatory design) and careful scrutiny of policies that would drive design or change the workflow.

Table 11: Study Recommendations for HIT Improvement

Recommendation	Publications
Interface Design	Ash (2004), Campbell (2006), Cochran, Horsky, Magrabi (2010), Magrabi (2012), Patterson, Wetterneck
Training & Education	Ash (2004), Cochran, Horsky, Magrabi (2010), Patterson, Santell
UI Standards or System Standards	Campbell (2009), Han, Kopell (2008), Magrabi (2010), Magrabi (2012), Wetterneck
More HIT Research on Workarounds, User Behavior or HIT Use	Ash (2004), Campbell (2009), Cochran, Eslami, Koppel (2005), Koppel (2008)
Improved CDS	Eslami, Santell, Walsh, Wetterneck
System Design to Meet Workflow	Ash (2004), Koppel (2008), Magrabi (2012), Patterson
Participatory Design	Ash (2004), Campbell (2006), Campbell (2009)
System Integration	Campbell (2009), Magrabi (2010), Santell
Increased and Careful Scrutiny of Policies Driving Design	Campbell (2009), Patterson, Wetterneck
Continuous Improvement and Monitoring of Implementations	Koppel (2005), Santell, Wetterneck
Increase Open Workspace and Lines of Communication Between Professionals	Campbell (2009), Patterson
Stable IT and Network Infrastructure	Magrabi (2010), Magrabi (2012)
Improved Safety Features in System	Magrabi (2010), Magrabi (2012)
Flexible Systems allow Deviation from Workflow	Patterson, Santell
Improved testing prior to implementation	Koppel (2008)
Back-up or Mirror System for Downtime	Magrabi (2010)

In addition to the recommendations identified in the studies analyzed for this thesis, there are a number of other recommendations from work that has been published recently or organizations that have published guidelines. These recommendations are concurrent with the recommendations from the analysis of the 18 studies selected for this thesis.

A recent paper published in the Journal of the American Medical Informatics Association outlined three primary recommendations: (Karsh et al., 2010)

1. Using multidisciplinary teams to develop and analyze information systems and technology used in healthcare. The recommended experts for teams include human factors engineers, applied psychologists, medical sociologists, communication scientists, cognitive scientists and interaction designers.
2. Increased research in "how clinical work is actually done and should be done." This research, according to the article, should be conducted using cognitive field analyses, cognitive work analysis, cognitive task analysis, workflow and task analysis and usability testing to develop detailed metrics into system use and clinical workflows.
3. The measurements to determine meaningful use should ensure what is measured actually allow a determination of whether the use is meaningful or not.

Another recent publication called for more precise metrics in tracking rates of harm and adverse events related to HIT. (Coiera et al., 2012) In addition, this article also urged the profession to develop means of examining the root cause of events and to enact methods that will allow overrides in the event of catastrophic failures in a system.

An article from the Journal of the American Medical Association outlines 8 guiding principles for safe implementation and use of HIT. (Sittig & Singh, 2009) They are:

1. Choosing the right hardware and software to ensure stability of systems and no interruption in workflow;
2. Ensuring the right content exists by choosing the right controlled vocabularies and medical terminological sets;
3. Developing the correct user interface to allow for simpler assimilation and interpretation of complex information sets;
4. Appropriately trained and educated personnel who understand the uses of the system to include clinicians and IT professionals;
5. The correct workflow and communication between professionals should be tested prior to system implementation and the system should not hinder such activities;
6. The organizational culture should be one of safety and have an attitude conducive to continual quality improvement;
7. The right regulations and policies can improve the state of healthcare including federal regulations and state regulations. These regulations should strive for safety as a primary concern;
8. The right monitoring to include pre-implementation and post-implementation inspections, certifying organizations for healthcare technologies and a call for hazard reporting databases from vendors will greatly increase the safety of HIT.

The Joint Commission has also made a set of recommendations in a recent Sentinel Alert. (Commission, 2009) These recommendations total 13 and are supported in the literature as well as being concurrent with the recommendations above. They include:

1. Mapping the workflow prior to systems implementation to avoid costly and dangerous errors;
2. Involving clinicians in the design process and seeking their input;
3. Assessing organizational IT needs beforehand and encouraging IT professionals to seek use cases beyond their organization;

4. Increased monitoring during implementation phases and increased available support to end-users;
5. Developing tailored training for clinicians of all types;
6. Ensuring policies dictate staff to contact for support;
7. Ensuring all order sets and guidelines are tested on paper and approved prior to "going live" with the system;
8. Improving alert systems using a "graduated set" of increasing alerts (improved algorithms based on priority of alert);
9. Irregular medication orders or those that circumvent normal routine should be reviewed by pharmacy;
10. Minimizing distractions at computer terminals and stations;
11. Continuously monitoring for safety events after implementation;
12. Monitoring and investigating adverse events and near misses;
13. Reevaluating systems for security, safety and HIPAA compliance when new technologies are connected to or added to the existing system.

The IOM has also made recommendations in "Health IT and Patient Safety: Building Safer Systems for Better Care." (Safety et al., 2012) This publication spans more than 200 pages and represents a committee of healthcare professionals tasked with identifying the requirements for building safer HIT. These recommendations follow suit with the recommendations listed above. The committee specifically underscores systems integration (interoperability and language bridging terminologies such as LOINC) and user interface design as primary focal points to improving HIT. In addition, they make specific recommendations for the process of implementation and testing of systems to include recommendations targeting proprietary vendors. They also outline "Eight Golden Rules of Interface Design."

Designing for consistency is the first recommendation and refers to consistency of the interface where controls for completing actions are consistent, data displays are consistent and there is a general sense of cohesion in the

system's interface. A second recommendation is to develop a sense of "international usability" so the system is easy to use for those with less experience and there are shortcuts for expert users. Developing feedback that actually informs the user as to why the error occurred and what actions can be taken to correct it is a rule as well. Using prompts within the system to guide the user, providing feedback and informing the user when actions (or series of actions) are complete acts as the fourth rule. Building a system that prevents errors is also a rule. This is a recommendation that states contextual awareness is important when developing choices in a system and allowing commands that can conflict or cause problems should be avoided. Allowing forgiveness (the ability to correct one's actions) for errors is the sixth rule. Supporting an internal locus of control comprises the seventh rule and refers to avoiding automation surprise in a system. Last, interfaces that require a professional to remember large amounts of information in order to complete an action (cognitive overload) should be avoided as well.

The recommendations from within the study and those published in articles or formal recommendations from prominent organizations within healthcare were concurrent on a number of topics. By far, user interface design and better interface development was a top recommendation. Human-Computer Interaction and good interface design are key concepts in building better and safer systems as they have a high representation in the literature surrounding both HIT-induced errors and patient safety related to technology. The development of interface testing standards and checklists for interface development are both trending recommendations as well as methods enabling better interface design with fewer error-prone systems. Developing systems with a solid IT infrastructure that are reliable and result in no unexpected downtime is a realistic requirement in the world of technology today with mirror systems and back-up systems to aid in emergency situations. Solid software development is a closely associated requirement that is often included in solid IT infrastructure and has been mentioned as inherent to safe HIT in a number of studies and article recommendations. Solid software development is an overarching category

including not only the development cycle of the software, but also key improvements in programming with increased functionality around CDS, safety features built into systems and improved feedback mechanisms to include better alerts, tiered alerts that are progressive in the severity of warnings and clear directives programmed into the software. Systems also need to have an ability to exchange information through the use of common and available health terminologies – a concept often referred to in this thesis as systems integration. Modeling the appropriate workflow is also a prevalent recommendation and involves appropriate requirements gathering as well as pre-implementation and post-implementation testing procedures that are rigorous. This also includes a top recommendation in the constant monitoring of systems for safety issues and timely response to issues compromising patient safety or safety within the system. Best practices will also heavily involve the users through participatory design and multi-disciplinary teams aiding in the development of new systems and improvement of existing systems. Finally, training is a trend within the literature and training should be tailored appropriately for specific groups. Out-of-the-box training programs and one-size-fits-all approaches are problematic and result in educational gaps for the end-users.

These recommendations are a positive step forward in developing a set of best practices in building, implementing and improving the safety of HIT in healthcare. Developing a set of regulatory requirements that are steeped in best practices and derived from known safety issues in the literature will provide the first layer of a solid foundation for better systems, better care and safer practice.

Discussion

This study sought to evaluate the negative effects of HIT through an integrative literature review, qualitative data analysis and the development of a taxonomic classification system of HIT-induced errors as reported in the literature. In addition, this study also sought to both identify the prevalence and impact of HIT-induced errors as well as identify the recommended best practices in addressing these types of errors. This discussion will serve as a commentary on

the literature review, the data analysis, the prevalence and impact of HIT and the recommended best practices.

Eighteen studies were located for this review – two of which were small case studies, but worthy of inclusion. As noted in several of the articles evaluated, the research on HIT-induced errors and adverse consequences is entirely too small. (Ash et al., 2004; Campbell et al., 2009; Cochran et al., 2007; Eslami et al., 2006; Koppel et al., 2005; Koppel et al., 2008) To be fair, this is a difficult area to study and reporting standards are far from perfect. (Coiera et al., 2012) The reporting of errors related to technology can provide heightened insight as to the causes and means to address them in future system development. Though reporting systems do exist, many are voluntary but still provide rich data with which to view HIT-induced errors. These methods informed 5 of the 18 studies. The primary means of data gathering was qualitative with observations, ethnographies, chart reviews and user interviews common across the studies. These methods and types of studies are not always easy to get approval for and thus may account for the small number of studies available in the medical literature. However, another problem is the nature of gaining data in a real environment where error is concerned. A good number of studies using simulations or usability testing were located when executing the literature review. But these studies were excluded. While the literature review did result in a large set of data and clear trends were seen within the data, the amount of research in this field is disappointing given the severity of the topic.

The data analysis for this study resulted in 8 primary categories and 30 subcategories within the primary categories. These categories were not only validated by the trending within the studies selected for review, but also by the authors of the studies and the recommendations for improved HIT from sources beyond the studies themselves. These categories provide a clear lens into the nature of errors in healthcare caused by HIT as well as a reference for future research in this area. As could be expected, the majority of the problems were technical in nature involving poor interface design, faulty programming or IT that simply was not reliable enough to support a high reliability organization like

healthcare. But issues such as systems mismatching the workflow, humans who found ways to work around systems and improper training, also compounded these problems. Also revealed were sociotechnical issues and unintended consequences as a result of HIT implementation. The results of the data analysis are not particularly surprising. There are a number of industries where automation has caused the same dire consequences such as the aviation industry and nuclear power plants. (Karsh et al., 2010) The problems in these examples were sometimes of a greater consequence and danger than the issues involving HIT-induced errors. These industries were able to overcome this through the investigation and re-modeling of errors along with involving subject experts such as human factors engineers, psychologist and sociologists. Thus the data analyzed in this study serves as a step in addressing and understanding the nature of HIT-induced errors.

It was possible to gain insight into the prevalence and impact of HIT-induced errors through the literature review for this study analyzing the representation of studies per technology. Additionally, it was possible to ascertain the significance of the subject through publications and works not included in the literature review for this study. With the exception of CPOE, there was minimal representation of CDS, BCMA and studies evaluating all technologies (or multiple system types) as a singular study analysis. A number of authors from the integrated review studies made recommendations for more research in this area. The integration of standards and increased research are also priorities for organizations with oversight of the safety and improvement of healthcare and standards. (Armijo, McDonnell, & Werner, 2009; Commission, 2009; Safety et al., 2012; Schumacher & Lowry, 2010) Though it is difficult to gain any quantitative sense of the impact of HIT-induced errors in the industry, these studies, publications and calls for research and standards serve as a marker for the significance of the subject. However, the lack of solid quantitative research with the ability to gain some measure of precision in regards to the prevalence and impact of HIT-induced errors is disappointing in an industry where metrics and scientific measurement are foundational to the profession. It will be difficult – if

not impossible – to determine whether any movement forward in developing and maintaining health information technologies has had a positive or negative impact without an accurate baseline. The baseline with which to measure any improvements in healthcare technologies can only be established through accurate representations or metrics of where the technologies stand today.

This study identified numerous sets of recommendations from the studies identified in the literature review, from prominent researchers in the profession and authoritative organizations within the healthcare industry. Of the numerous recommendations identified, there was considerable concurrence among them. The recommendations also concur (or address) the errors identified as a result of this study. These recommendations from groups such as the IOM represent a step forward for the healthcare industry in addressing the adverse effects of HIT. However, it is disappointing in an industry so steeped in regulation, measurements and standards that there has not been a push for EMR standards until recently. HealthIT.gov is a step in the right direction providing guidance for practices and organizations. But it remains to be seen whether the standards put in place for Meaningful Use Criteria will have the desired impact or the specificity to address the major problems HIT has encountered over the past decade. Moreover, these standards are still in a state of flux, untested and have not been validated. There is reason to be positive and some recent publications show HIT as having significant benefits. (Buntin, Burke, Hoaglin, & Blumenthal, 2011; Chaudhry et al., 2006; Shekelle, Morton, & Keeler, 2006) But as American Medical Informatics Association noted in a recent publication, (Bloomrosen et al., 2011) there has not been enough research into the effects of HIT and much of the research has been completed during a period of slow HIT uptake. The development of rigorous standards that can be measured and show clear benefits as well as standards that will address the adverse effects of HIT still remain a spot on the horizon.

Limitations of Study

There are a number of limitations of this study – the foremost of which is the ability to "map an error." Reason's Model of Human Error and the Swiss Cheese Model note an error is not normally the result of a single cause, but a number of conditions, which when met, all converge to form an error. In short, an error is difficult to attribute to a single cause. This makes it difficult to categorize an error with a single label. There are many errors identified within the studies that were either difficult to determine any cause for or difficult to label with a single cause. Many errors are the result of federal regulations, guidelines or institutional policies guiding the design of the system. A number of the errors identified, for example, started with interface design problems and cascaded into other categories such as workflow, cognitive overload or a workaround. The taxonomic representation addresses this factor in some respects. But, a taxonomy that provides a cross-listing or cross-directory may help in alleviating the problem of mapping an error.

This study limited the literature search to the past decade, in part, to address the slow uptake of HIT in the nineties and also to ensure the progress in HIT was represented in the selected studies. However, there has still been a relatively slow adoption of HIT in even the past decade. (Jha et al., 2009) This poses an obvious limitation in evaluating HIT use and implementations. There may not be a representative sample yet available in which to evaluate the errors or adverse effects of HIT in healthcare. In addition, only 7 of the 18 studies – less than half – represented more than a single institution. The nature of this type of research and the subject matter makes collecting data problematic. The lack of representative research on a wide scale and the slow adoption of HIT is a limitation that currently cannot be overcome. It is, however, not a limitation that in any way reduces the importance of this work or negates reasons for pursuing the problems evident in what research does exist.

There is, generally speaking, a lack of quantitative means to measure the impact or improvement in HIT-induced errors. This compounds the problems in setting standards or developing guidelines to the improve HIT. Whether

Meaningful Use will result in "meaningful measurements" or insights into the associated problems in HIT and the impact remain to be seen.

Though there are obvious limitations to the nature of this work and research in this particular area of healthcare, it does not suggest one should adopt a nihilist perspective and ignore the obvious warning signs in an industry with marked struggles ahead of it in the next decade. The limitations exist as they do and identifying them provides an opportunity to minimize or eliminate them for better healthcare in the future.

Future Research

Future research into the adverse effects of HIT should move in a number of directions. First and foremost, the studies and research that have been completed should continue and there clearly needs to be more of it. In addition, representations and descriptions of the types of errors and adverse consequences of HIT should be a continuing agenda in healthcare as these are means to understand the nature and cause of the errors. Whether these representations exist in the form of taxonomies or as a guidebook of errors, does not matter so much as that they exist and are used to inform future guidelines and recommendations. In addition, research into the specific technologies used in healthcare could provide additional insight into the types of errors. For example, evaluating interface design and usability studies of HIT can inform the current research with more granular data. Evaluating only BCMA and the errors and usability issues can provide more granular data related to only that technology. Research like this would allow representations such as that of Magarabi and colleagues (Magrabi et al., 2010, 2011, 2012) and the research conducted in this thesis to be filled in with more detail. Finally, there is an obvious limitation to the metrics and measurements to ascertain the impacts of HIT, the errors resulting from HIT and whether recommended guidelines will actually impact baseline measurements.

Conclusion

The results of this study indicate there is significant reason to warrant concern in evaluating HIT-induced errors and adverse consequences. This study located 18 articles and 228 identified adverse effects of HIT in healthcare including technologies such as CPOE, CDS, BCMA and studies evaluating multiple systems. These adverse effects trended and were cohesive allowing the development of a classification and taxonomic representation of adverse effects within HIT. This study also serves as a window into viewing the prevalence and impact of HIT-induced errors and adverse consequences as well as providing recommendations for the improvement of such technologies in healthcare.

References

Ammenwerth, E., Talmon, J., Ash, J. S., Bates, D. W., Beuscart-Zéphir, M. C., Duhamel, A., . . . Geissbuhler, A. (2006). Impact of CPOE on mortality rates--contradictory findings, important messages. *Methods of Information in Medicine*, *45*(6), 586-593.

Armijo, D., McDonnell, C., & Werner, K. (2009). Electronic health record usability. *Interface Design Considerations. Rockville, MD: Agency for Healthcare Research and Quality, US Department of Health and Human Services.*

Ash, J. S., Berg, M., & Coiera, E. (2004). Some unintended consequences of information technology in health care: The nature of patient care information system-related errors. *Journal of the American Medical Informatics Association : JAMIA*, *11*(2), 104-112.

Ash, J. S., Sittig, D. F., Campbell, E., Guappone, K., & Dykstra, R. H. (2006). An unintended consequence of CPOE implementation: Shifts in power, control, and autonomy. *AMIA Annual Symposium Proceedings / AMIA Symposium. AMIA Symposium*, 11-15.

Ash, J. S., Sittig, D. F., Campbell, E. M., Guappone, K. P., & Dykstra, R. H. (2007). Some unintended consequences of clinical decision support systems. *AMIA Annual Symposium Proceedings / AMIA Symposium. AMIA Symposium*, 26-30.

Ash, J. S., Sittig, D. F., Dykstra, R., Campbell, E., & Guappone, K. (2007). Exploring the unintended consequences of computerized physician order entry. *Studies in Health Technology and Informatics*, *129*(Pt 1), 198-202.

Ash, J. S., Sittig, D. F., Dykstra, R., Campbell, E., & Guappone, K. (2009). The unintended consequences of computerized provider order entry: Findings from a mixed methods exploration. *International Journal of Medical Informatics*, *78 Suppl 1*, S69-76.

Ash, J. S., Sittig, D. F., Dykstra, R. H., Guappone, K., Carpenter, J. D., & Seshadri, V. (2007a). Categorizing the unintended sociotechnical consequences of computerized provider order entry. *International Journal of Medical Informatics*, *76 Suppl 1*, S21-27.

Ash, J. S., Sittig, D. F., Poon, E. G., Guappone, K., Campbell, E., & Dykstra, R. H. (2007b). The extent and importance of unintended consequences related to computerized provider order entry. *Journal of the American Medical Informatics Association: JAMIA*, *14*(4), 415-423.

Ash, J. S., Stavri, P. Z., & Kuperman, G. J. (2003). A consensus statement on considerations for a successful CPOE implementation. *Journal of the American Medical Informatics Association: JAMIA*, *10*(3), 229-234.

Bates, D. W. (2005). Computerized physician order entry and medication errors: Finding a balance. *Journal of Biomedical Informatics*, *38*(4), 259-261.

Bates, D. W., Leape, L. L., Cullen, D. J., Laird, N., Petersen, L. A., Teich, J. M., . . . Seger, D. L. (1998). Effect of computerized physician order entry and a

team intervention on prevention of serious medication errors. *JAMA: The Journal of the American Medical Association*, *280*(15), 1311-1316.
Beyea, S., & Nicoll, L. H. (1998). Writing an integrative review. *AORN*, *67*(4), 877-80.
Bloomrosen, M., Starren, J., Lorenzi, N. M., Ash, J. S., Patel, V. L., & Shortliffe, E. H. (2011). Anticipating and addressing the unintended consequences of health IT and policy: A report from the AMIA 2009 health policy meeting. *Journal of the American Medical Informatics Association: JAMIA*, *18*(1), 82-90.
Borycki, E. M., Kushniruk, A. W., Keay, L., & Kuo, A. (2009). A framework for diagnosing and identifying where technology-induced errors come from. *Studies in Health Technology and Informatics*, *148*, 181-187.
Buntin, M. B., Burke, M. F., Hoaglin, M. C., & Blumenthal, D. (2011). The benefits of health information technology: A review of the recent literature shows predominantly positive results. *Health Affairs, 30*(3), 464-471.
Campbell, E. M., Guappone, K. P., Sittig, D. F., Dykstra, R. H., & Ash, J. S. (2009). Computerized provider order entry adoption: Implications for clinical workflow. *Journal of General Internal Medicine*, *24*(1), 21-26.
Campbell, E. M., Sittig, D. F., Ash, J. S., Guappone, K. P., & Dykstra, R. H. (2006). Types of unintended consequences related to computerized provider order entry. *Journal of the American Medical Informatics Association: JAMIA*, *13*(5), 547-556.
Campbell, E. M., Sittig, D. F., Guappone, K. P., Dykstra, R. H., & Ash, J. S. (2007). Overdependence on technology: An unintended adverse consequence of computerized provider order entry. *AMIA Annual Symposium Proceedings / AMIA Symposium. AMIA Symposium*, 94-98.
Chaudhry, B., Wang, J., Wu, S., Maglione, M., Mojica, W., Roth, E., Shekelle, P. G. (2006). Systematic review: Impact of health information technology on quality, efficiency, and costs of medical care. *Annals of Internal Medicine*, *144*(10), 742-752.
Cochran, G. L., Jones, K. J., Brockman, J., Skinner, A., & Hicks, R. W. (2007). Errors prevented by and associated with bar-code medication administration systems. *Joint Commission Journal on Quality and Patient Safety/Joint Commission Resources*, *33*(5), 293-301.
Coiera, E., Aarts, J., & Kulikowski, C. (2012). The dangerous decade. *Journal of the American Medical Informatics Association: JAMIA*, *19*(1), 2-5.
Commission, J. (2009). *Sentinel event alert issue 42. Safely implementing health information and converging technologies* [Web page]. Retrieved from Google Scholar.
Cooper, H. M., & Cooper, H. M. (1998). *Synthesizing research* (3, illustrated, reprint ed., p. 201). Thousand Oaks, Calif.: SAGE.
C*rossing the Quality Chasm: A New Health System for the 21st Century.* (2001). *Crossing the quality chasm: A new health system for the 21st century.* Washington, D.C.: National Academy Press.

Del Beccaro, M. A., Jeffries, H. E., Eisenberg, M. A., & Harry, E. D. (2006). Computerized provider order entry implementation: No association with increased mortality rates in an intensive care unit. *Pediatrics*, *118*(1), 290.

Dykstra, R. H., Ash, J. S., Campbell, E., Sittig, D. F., Guappone, K., Carpenter, J., McMullen, C. (2009). Persistent paper: The myth of "going paperless". *AMIA Annual Symposium Proceedings / AMIA Symposium. AMIA Symposium*, *2009*, 158-162.

Eslami, S., Abu-Hanna, A., de Keizer, N. F., & de Jonge, E. (2006). Errors associated with applying decision support by suggesting default doses for aminoglycosides. *Drug Safety*, *29*(9), 803-809.

Furukawa, M. F., Raghu, T. S., Spaulding, T. J., & Vinze, A. (2008). Adoption of health information technology for medication safety in U.S. Hospitals, 2006. *Health Affairs*, *27*(3), 865-875.

Goddard, K., Roudsari, A., & Wyatt, J. (2011a). Decision support and automation bias: Methodology and preliminary results of a systematic review. *Studies in Health Technology and Informatics*, *164*, 3-7.

Goddard, K., Roudsari, A., & Wyatt, J. C. (2011b). Automation bias--a hidden issue for clinical decision support system use. *International Perspectives In Health Informatics*, 164, 17-22.

Goddard, K., Roudsari, A., & Wyatt, J. C. (2012). Automation bias: A systematic review of frequency, effect mediators, and mitigators. *Journal of the American Medical Informatics Association: JAMIA*, *19*(1), 121-127.

Han, Y. Y., Carcillo, J. A., Venkataraman, S. T., Clark, R. S. B., Watson, R. S., Nguyen, T. C., . . . Orr, R. A. (2005). Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system. *Pediatrics*, *116*(6), 1506-1512.

Harrison, M. I., Koppel, R., & Bar-Lev, S. (2007). Unintended consequences of information technologies in health care--an interactive sociotechnical analysis. *Journal of the American Medical Informatics Association: JAMIA*, *14*(5), 542-549.

Himmelstein, D. U., Wright, A., & Woolhandler, S. (2010). Hospital computing and the costs and quality of care: A national study. *The American Journal of Medicine*, *123*(1), 40-46.

Hofer, T. P., Kerr, E. A., & Hayward, R. A. (2000). What is an error? *Effective Clinical Practice: ECP*, *3*(6), 261-269.

Horsky, J., Kuperman, G. J., & Patel, V. L. (2005). Comprehensive analysis of a medication dosing error related to CPOE. *Journal of the American Medical Informatics Association: JAMIA*, *12*(4), 377-382.

Jha, A. K., DesRoches, C. M., Campbell, E. G., Donelan, K., Rao, S. R., Ferris, T. G., Blumenthal, D. (2009). Use of electronic health records in US hospitals. *New England Journal of Medicine*, *360*(16), 1628-1638.

Kalra, J. (2004). Medical errors: An introduction to concepts. *Clinical Biochemistry*, *37*(12), 1043-1051.

Karsh, B. T., Weinger, M. B., Abbott, P. A., & Wears, R. L. (2010). Health information technology: Fallacies and sober realities. *Journal of the American Medical Informatics Association: JAMIA*, *17*(6), 617-623.

Kohn, L. T., Corrigan, J., & Donaldson, M. S. (2000). *To err is human : Building a safer health system* (illustrated ed., p. 287). Washington, D.C.: National Academies Press.

Koppel, R. (2005). What do we know about medication errors made via a CPOE system versus those made via handwritten orders? *Critical Care (London, England)*, *9*(5), 427-428.

Koppel, R., Metlay, J. P., Cohen, A., Abaluck, B., Localio, A. R., Kimmel, S. E., & Strom, B. L. (2005). Role of computerized physician order entry systems in facilitating medication errors. *JAMA: The Journal of the American Medical Association*, *293*(10), 1197-1203.

Koppel, R., Wetterneck, T., Telles, J. L., & Karsh, B. T. (2008). Workarounds to barcode medication administration systems: Their occurrences, causes, and threats to patient safety. *Journal of the American Medical Informatics Association: JAMIA*, *15*(4), 408-423.

Lisby, M., Nielsen, L. P., Brock, B., & Mainz, J. (2010). How are medication errors defined? A systematic literature review of definitions and characteristics. *International Journal for Quality in Health Care : Journal of the International Society for Quality in Health Care / ISQua*, *22*(6), 507-518.

Magrabi, F., Ong, M. S., Runciman, W., & Coiera, E. (2010). An analysis of computer-related patient safety incidents to inform the development of a classification. *Journal of the American Medical Informatics Association: JAMIA*, *17*(6), 663-670.

Magrabi, F., Ong, M. S., Runciman, W., & Coiera, E. (2011). Patient safety problems associated with heathcare information technology: An analysis of adverse events reported to the US food and drug administration. *AMIA Annual Symposium Proceedings / AMIA Symposium. AMIA Symposium*, *2011*, 853-857.

Magrabi, F., Ong, M. S., Runciman, W., & Coiera, E. (2012). Using FDA reports to inform a classification for health information technology safety problems. *Journal of the American Medical Informatics Association: JAMIA*, *19*(1), 45-53.

Niazkhani, Z., Pirnejad, H., Berg, M., & Aarts, J. (2009). The impact of computerized provider order entry systems on inpatient clinical workflow: A literature review. *Journal of the American Medical Informatics Association: JAMIA*, *16*(4), 539-549.

Niazkhani, Z., Pirnejad, H., van der Sijs, H., & Aarts, J. (2011). Evaluating the medication process in the context of CPOE use: The significance of working around the system. *International Journal of Medical Informatics*, *80*(7), 490-506.

Patterson, . S. (2002). Improving patient safety by identifying side effects from introducing bar coding in medication administration. *Journal of the American Medical Informatics Association: JAMIA*, *9*(5), 540-553. doi:10.1197/jamia.M1061

Patton, M. Q. (1999). Enhancing the quality and credibility of qualitative analysis. *Health Services Research*, *34*(5 Pt 2), 1189-1208.

Pedersen, C. A., & Gumpper, K. F. (2008). ASHP national survey on informatics: Assessment of the adoption and use of pharmacy informatics in U.S. Hospitals--2007. *American Journal of Health-system Pharmacy: AJHP: Official Journal of the American Society of Health-System Pharmacists*, *65*(23), 2244-2264.

Poon, E. G., Keohane, C. A., Yoon, C. S., Ditmore, M., Bane, A., Levtzion-Korach, O., . . . Gandhi, T. K. (2010). Effect of bar-code technology on the safety of medication administration. *The New England Journal of Medicine*, *362*(18), 1698-1707.

Reason, J. (2000). Human error: Models and management. *BMJ (Clinical Research Ed.)*, *320*(7237), 768-770.

Reid, P. P., Compton, W. D., Grossman, J. H., & Fanjiang, G. (2005). *Building a better delivery system : A new engineering* (illustrated ed., p. 262). Washington, D.C.: National Academies Press.

Rodgers, B. L., & Knafl, K. A. (2000). *Concept development in nursing : Foundations, techniques, and applications* (2, illustrated ed., p. 458). Philadelphia: Saunders.

Safety, C. O. P., Technology, H. I., & Medicine, I. O. (2012). *Health IT and patient safety: Building safer systems for better care.* National Academies Press.

Santell, J. P., Kowiatek, J. G., Weber, R. J., Hicks, R. W., & Sirio, C. A. (2009). Medication errors resulting from computer entry by nonprescribers. *American Journal of Health-system Pharmacy: AJHP: Official Journal of the American Society of Health-System Pharmacists*, *66*(9), 843-853.

Schumacher, R. M., & Lowry, S. Z. (2010). NIST guide to the processes approach for improving the usability of electronic health records. *National Institute of Standards and Technology.*

Shekelle, P. G., Morton, S. C., & Keeler, E. B. (2006). Costs and benefits of health information technology. *Evidence Report/technology Assessment*, (132), 1-71.

Silverman, D. C. (n.d.). The electronic medical record system: Health care marvel or morass? *Physician Executive*, *24*(3), 26 -30.

Sittig, D. F., & Singh, H. (2009). Eight rights of safe electronic health record use. *JAMA: The Journal of the American Medical Association*, *302*(10), 1111-1113.

Sittig, D. F., & Singh, H. (2010). A new sociotechnical model for studying health information technology in complex adaptive healthcare systems. *Quality & Safety in Health Care*, *19 Suppl 3*, i68-74.

Sittig, D. F., & Singh, H. (2011). Defining health information technology-related errors: New developments since to err is human. *Archives of Internal Medicine*, *171*(14), 1281-1284.

Sittig, D. F., Ash, J. S., Zhang, J., Osheroff, J. A., & Shabot, M. M. (2006). Lessons from" unexpected increased mortality after implementation of a commercially sold computerized physician order entry system". *Pediatrics*, *118*(2), 797-801.

Tamuz, M. (2004). Defining and classifying medical error: Lessons for patient safety reporting systems. *Quality and Safety in Health Care*, *13*(1), 13-20.

The Joint Commision. (2009). Latest sentinel event alert focuses on technology-related errors. *Hosp Peer Rev*, *34*(2), 13-5.

Wachter, R. M. (2006). Expected and unanticipated consequences of the quality and information technology revolutions. *JAMA: The Journal of the American Medical Association*, *295*(23), 2780-2783.

Walsh, K. E., Adams, W. G., Bauchner, H., Vinci, R. J., Chessare, J. B., Cooper, M. R., Landrigan, C. P. (2006). Medication errors related to computerized order entry for children. *Pediatrics*, *118*(5), 1872-1879.

Wetterneck, T. B., Walker, J. M., Blosky, M. A., Cartmill, R. S., Hoonakker, P., Johnson, M. A., . . . Carayon, P. (2011). Factors contributing to an increase in duplicate medication order errors after CPOE implementation. *Journal of the American Medical Informatics Association: JAMIA*, *18*(6), 774-782.

Whittemore, R., & Knafl, K. (2005). The integrative review: Updated methodology. *Journal of Advanced Nursing*, *52*(5), 546-553.

Christopher L. Kiess

632 Cahill Lane | Indianapolis, IN 46214 | 317.446.0163
Email: ckiess@iupui.edu | website: http://chriskiess.net/

Education

Master of Science, Indiana University School of Informatics, Degree expected Fall, 2012
Master of Library Science, Indiana University School of Library and Information Science GPA 3.9/4.0, Graduated December 2006.
B.A. in English and Philosophy, Indiana University School of Liberal Arts 3.9/4.0 GPA, Dean's List all Semesters, Graduated with Highest Distinction May, 2004.

Professional Experience

2011- 2012 Avanade, Inc. – Consultant, UX Architect

- Designed and prototyped Electronic Medical Record (EMR) System and solutions with Amedisys Home Health to improve existing design
- Responsible for moving the product from conceptualization to the design phase conducting business analysis, developing and refining business rules and developing design solutions that enable end-user efficiency
- Drove modules within the project through iterative development via client meetings and presentations to refine designs and ensure stakeholder approval

2011- 2012 National Alzheimer's Association – Assoc. Director, Information Architecture

- Responsible for both internal and external web assets, the organization and the architecture of electronic assets
- Management of terminological sets (taxonomies, controlled vocabularies, thesauri) for the categorization and classification on electronic content
- Consulting in Search Engine Optimization (SEO) and enabling both the visibility and findability of e-content

2010 – 2011 Indiana University Center for Aging Research (IUCAR) – Health Informatics Project Manager

- Responsible for the coordination of Informatics needs and solutions on IUCAR grants, contracts and research projects managing all phases from conception to implementation
- Developed and managed the IT needs of the organization to include server management and desktop support
- Managed application development, application security and EMR HIPAA compliance

2010 – 2012 IUPUI School of Library & Information Science – Adjunct Faculty

- Curriculum development for both S554 (Library Systems) and S503 (Organization and Representation of Knowledge and Information)

- Experience in porting in-class materials to an online format and environment
- Employed the use of dynamic teaching materials for both in-class and online courses to include podcasts, web development, video streaming and screencasting

2008-2010 Regenstrief Institute – Research Coordinator

- Coordinated IT Initiatives for federal research projects working closely with the IU School of Medicine, CDC, AHRQ and the Veteran's Administration
- Served as primary lead on prototyping effort for Clinical Decision Support system of VA Vista Colorectal Screening under the AHRQ 8 ACTION grant
- Led major design and usability efforts for clinical information systems under the AHRQ 8 ACTION grant and AHRQ National Hospital Acquired Infection collaboration

2006-2008 Columbus Regional Hospital – Information & Knowledge Specialist

- Routinely consulted and worked directly with the CNS staff to guide research projects and agendas from the beginning stages of the research process to implementation
- Managed all aspects of Information Services to include collection development, budgeting, acquisitions and reference and research for physicians and healthcare professionals across the organization
- Conducted research and developed lectures and presentations for committees and staff on information literacy, online information retrieval and patient education

Other Experience

2004-2007	IUPUI Department of Liberal Arts – Adjunct Faculty/Instructor
2003-2004	IUPUI *Sagamore* – Photo Editor/News Writer
1998-2002	Navistar International – Assembly & Production
1990-1996	United States Marine Corps – Non-Commissioned Officer Honorably Discharged

---

Publications & Presentations

Doebbeling, B.N., Saleem, J., Haggstrom, D., Militello, L., Flanagan, M., Arbuckle, C., Kiess, **C**. Final Report: "Integrating Clinical Decision Support Into Workflow", Agency for Healthcare Research and Quality (AHRQ), ACTION Award Number: HSA290200600013-3, Washington, D.C., 2011.

Doebbeling BN, Saleem JJ, Haggstrom DA, Militello LG, Flanagan M, Kiess CL, & Arbuckle N. Investigating Integration of Computerized Decision Support into Workflow at Three Benchmark Institutions. 2011 VA Health Services Research and Development (HSR&D) National Meeting.

Flanagan M, Doebbeling BN, Welsh A, Hoke S & Kiess CL. A National Collaborative in Reducing Healthcare Associated Infections: Current Initiatives, Challenges and Opportunities. *American Journal of Infection Control.* 2011 Oct;39(8):685-9.

Saleem JJ, Haggstrom DA, Militello LG, Flanagan M, Kiess CL, Arbuckle N, & Doebbeling BN. Impact of a Redesign for Colorectal Cancer Screening Computerized Decision Support. 2011 VA Health Services Research and Development (HSR&D) National Meeting.

Saleem JJ, Haggstrom DA, Militello LG, Flanagan M, Kiess CL, Arbuckle N, Doebbeling BN. Redesign of a computerized clinical reminder for colorectal cancer screening: A human-computer interaction evaluation. *BMC Med Inform Decis Mak*. 2011; 11:74.

Welsh A, Flanagan ME, Kiess CL. Implementing the MRSA Bundle in ICUs: One City-wide Collaborative's Lessons and Successful Strategies. *Infection Control and Hospital Epidemiology*. 2011 Sep;32(9):918-21