THE STUDY OF ERRORS, EXPECTATIONS AND SKILLS FOR MEDICATION DELIVERY SYSTEMS IMPROVEMENT

by

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Lukasz Maciej Mazur

April, 2007

To my father, Henryk

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ABSTRACT

Medication errors occurring in hospitals are a growing national concern. The enormous gaps in knowledge related to medication errors are often seen as major reasons for increased patient safety risks and increased waste in the hospital setting. However, little research effort in industrial and management engineering has been devoted specifically to medication delivery systems to improve or optimize their operations in terms of patient safety and systems efficiency and productivity. As a result, the current literature does not offer integrated solutions to overcome the workflow and management difficulties with medication delivery. Therefore, a better understanding of workflow and management sources of medication errors is needed to help support decisions about investing in strategies to reduce medication errors. Using qualitative and quantitative research methods the work reported in this dissertation makes several contributions to the existing body of knowledge. First, using healthcare professionals' perceptions of medication delivery system, a set of simple and logical workflow design rules are proposed. If properly implemented, the proposed rules are capable of eliminating the unnecessary variations in the process of medication delivery which cause medication errors and waste. Second, a theoretical model of 'expectations' for effective management of medication error reporting, analysis and improvement is provided. The practical implication of this theoretical model extends to effective management strategies that can increase feelings of competence and help create a culture that values improvement efforts. Third, eight propositions for effective use of a systems engineering method (in this research the "Map-to-Improve" (M2I) method) for medication delivery improvement are offered. Finally, a set of skills needed for future healthcare professionals to effectively use systems engineering methods is provided. The proposed insights into these areas can result in improved pedagogy for professional development of healthcare professionals. The practical implication extends to the development of better methods for healthcare systems analysis. In summary, the author of this research work hopes that the findings and discussions will help healthcare organizations to achieve satisfactory improvement in medication delivery.

INTRODUCTION

Background and Motivation

In a 2006 report, the Institute of Medicine (IOM) suggested that medication errors are so common in hospitals that patients should expect to suffer at least one every day they remain hospitalized. As a result, it has been estimated that medication-related errors harm approximately 1.5 million people in the United States, costing the nation at least $3.5 billion annually (IOM, 2006). Past research suggested that between 60–80 percent of errors involve human error (Perrow, 1984). Yet, more recent research and analysis concluded that the majority of errors do not result from individual recklessness but more commonly by faulty systems, poor managerial decisions and conditions that lead people to make mistakes or fail to prevent them (National Wholesale Druggists' Association, 1998; Phillips et al., 1998; IOM, 2001, 2005, 2006; Tucker et al., 2002; Tucker and Edmondson, 2002, 2003; Weingart and Page, 2003; McFadden et al., 2004, 2006a,b; Ramanujam and Rosseua, 2006; Anderson et al., 2006; Ghosh and Sobek, 2007c). Clearly there must be enormous gaps in the knowledge required to understand and reduce the medication errors and the related costs. As a result, the current literature does not offer integrated solutions to overcome the systems and management difficulties with medication delivery. A better understanding of the sources of medication errors and their consequences of costs (or wastes) is needed to help support decisions about investing in strategies to reduce medication errors (or medication delivery errors).

When faced with medication error, healthcare professionals should first solve the immediate crisis. Second, they should report medication error in a safe and motivated fashion (Uribe et al., 2002). Finally, they should scientifically and jointly investigate the

system to find and remove the root causes to prevent error recurrence (Tucker et al., 2002; Tucker and Edmondson, 2002, 2003; Ghosh and Sobek, 2007c). However, the literature reports the lack of time for error reporting (Uribe et al., 2002; Tucker and Edmondson, 2002; Hillsden and Fenton, 2006), psychological issues with error reporting (Edmondson, 1999), and dominance of short-term approaches or work arounds to address problems in the healthcare industry (Tucker et al., 2002; Tucker and Edmondson, 2002, 2003; Ghosh and Sobek, 2007c). Diminishing levels of scientific problem solving have been also detected across various industries (Hayes et al., 1988; Feigenbaum, 1991; Blumenthal and Kilo, 1998; Shortell et al., 1998). To deal with these issues, many healthcare organizations tried to utilize different engineering methods/tools (IOM, 2005). However, the inefficient uses of such methods by healthcare professionals lead the organization's management to premature and negative conclusions about their fit to healthcare environment. As a result, it lowered the confidence in such methods as well as those who were called upon to use them. There are ample cases documented the poorly used engineering methods actually generated additional work for frontline providers and very little apparent reward (Boodman, 2005; Durieux, 2005; Garg et al., 2005; Wears and Berg, 2005). In addition, despite frequent recommendations to increase emphasis on medication safety, little educational effort has been devoted specifically to 'systems thinking' to improve or optimize the operations of medication delivery systems in terms of patient safety and systems efficiency and productivity (American Association of Colleges of Nursing, 1998; Health Resources and Services Administration, 2000). As a result, very few administrators, managers, nurses or technicians are equipped to analytically view their medication delivery processes as a system, nor appreciate the

relevance and benefits of a systems engineering approach for systems improvement (IOM, 2005). From our interdisciplinary research with the College of Nursing at Montana State University (MSU) and the field studies at one community hospital (CH), we found that neither nursing students nor healthcare professionals are provided with well designed (if any) methods/tools and education/training to help them improve the medication use systems (or medication delivery systems). We also found that neither healthcare professionals nor students are prepared to effectively use systems engineering methods/tools to improve the medications delivery systems. Despite such challenges, we believe that properly designed and deployed improvement strategies and methods for the analysis of medication use systems can result in effective and long-lasting improvement for reducing medication errors.

Proposed Research

To cross the quality gap in the 21st century's healthcare industry, the challenge is to manage the growing knowledge of healthcare systems and ensure that future health care workforce will have the skills they need to use it (IOM, 2005). The major objectives of this research are as follows:

First Research Objective

Research Objective #1: To identify the major workflow factors that cause medication delivery errors.

In this research, 12 different departments at CH were studied. With the data collected the author conducted statistical analysis to understand what are the major factors (i.e., technical complexity of tasks/connections, resources problems, and qualification of human resources) having significant effects on medication errors in

medication use systems. In this research, the author defines a medication delivery error as the execution of a task that is either unnecessary or incorrectly carried out and that could have been avoided with appropriate distribution of pre-existing information (IOM, 2006). After knowing the major factors causing medication errors, the managers will be able to continuously improve patient safety and to reduce system waste by concentrating on the most significant areas.

Second Research Objective

Research Objective #2: To understand the phenomena (i.e., motivation, group thinking, etc.) needed to stimulate and sustain medication error reporting, analysis and improvement by the frontline healthcare professionals (i.e., nurses and technicians) and managers.

Reducing medication errors is extremely vital to the healthcare industry in the upcoming years. However, the phenomena needed to stimulate and sustain medication error reporting, analysis and improvement are not well understood. Therefore, the author worked with 91 healthcare professionals to develop a theoretical model to help promote effective improvements of medication delivery systems.

Third Research Objective

Research Objective #3: To test and evaluate a systems engineering method, the "Map to Improve" (M2I) method, for medication delivery systems and learn how this method affects nursing students' individual and collaborative skills to analyze and solve medication delivery problems.

The ability to analyze problems with a systems approach is absolutely critical to the healthcare industry. However, the healthcare systems analysis and improvement performed by healthcare professionals are not well understood. Using a survey study, the author evaluated the impact of the M2I method (Mazur and Chen, 2007, 2008) on nursing students' individual and cooperative skills to analyze and solve medication delivery

problems. The outcome of this study resulted in propositions regarding the effective use of systems engineering method for analyzing and improving medication delivery systems.

Fourth Research Objective

Research Objective #4: To identify the skills needed for future healthcare professionals to effectively use systems engineering methods and determine how these skills can be developed.

The importance of properly preparing the future healthcare workforce cannot be underestimated (American Association of Colleges of Nursing, 1998; Health Resources and Services Administration, 2000; National Patient Safety Foundation, 2004). As the results from research objective #3 began to take shape, the author identified those skills that seem to lead to exceptional capabilities for medication delivery systems analysis and improvement. Any insight into this area will provide significant suggestions for professional development of healthcare professionals as well as the development of better methods and tools for healthcare delivery improvement.

LITERATURE REVIEW

Cost and Safety of Medication Errors

The Institute of Medicine (IOM) estimated that medication-related errors in all care settings harm approximately 1.5 million people in the US, costing the nation at least $3.5 billion annually (IOM, 2006). Most of what is known relates to additional healthcare costs associated with the preventable adverse drug events (ADE), which represent the injuries caused by errors. To comprehend the magnitude of medication errors, Figure 1 presents a story of Betsy Lehman – a victim of medication error. For hospital settings, one study shows the $5,857 extra cost of inpatient care was due to ADEs occurring while in the hospital (Bates et al., 1997). This study used data from 1993 and is considered quite dated. For ambulatory care, the best estimate can be derived from a study (Field et al., 2005) that 1000 older adults would have annual costs related to ADEs in the ambulatory setting of $65,631 with $27,365 of this associated with preventable events, while national annual costs were estimated at $887 million. For long-term care, Gurwitz and colleagues (2005) projected an annual incidence of 800,000 preventable ADEs. However, there is no estimate of the associated health care costs for this group of preventable ADEs.

According to Perrow's (1999) normal accident theory, medication errors are inevitable in complex industries like healthcare. In contrast, high reliability theory believes that accidents can be prevented through good organizational design and management (Sagan, 1993). Characteristics of highly reliable industries include an

Figure 1. Betsy Lehman Story: Magnitude of Medication Error [1]

Betsy Lehman, a 39-year-old wife and mother of two and health reporter for the Boston Globe, was diagnosed with breast cancer in September 1993. She was admitted to the Dana-Farber Cancer Institute in Boston on November 14, 1994, for her third round of cyclophosphamide, a toxic chemotherapy agent. Betsy was participating in a dose-escalating phase 1 clinical trial in which higher-than-normal doses of the drug were being administered to wipe out cancer cells. She was undergoing a bone marrow transplant to restore immune and blood forming cells. Betsy received the wrong dose of cyclophosphamide. The correct dose was 1,000 milligrams (mg) per square meter (m2) of body surface area, given each day for a total of 4 days (or, for her height and weight, a total of 4,000 mg/m2 or 6,520 mg infused over the 4-day course of therapy). But after reading the trial protocol, a physician fellow wrote the order as 4,000 mg/m2 x 4 days. The erroneous dosing went unrecognized, and Betsy died as a result of the overdose on December 3, 1993. The error was not discovered until 10 weeks later, when her treatment data were entered into the computer for the clinical trial (Bohmer, 2003; Bohmer and Winslow, 1999). Experts at the hospital, as well as outside consultants, recognized that many factors contributed to this tragedy (Conway and Weingart, 2005). System issues included minimal double checks, orders written by fellows without attending MD signoff, and unclear protocols that were not current and not easily available to RNs and pharmacists. Some dosages were written in total dose and some in daily dose formats, often in the same protocol. Maximum dose checking was not a feature of the pharmacy computer system. Both the patient and her family had felt that Betsy was not being listened to and mechanisms for reporting issues were not clear. When reporting did occur, it did not move up the organization in a timely fashion. Today, the hospital has a strong culture of safety and engages interdisciplinary groups of front-line clinicians in the design and implementation of chemotherapy protocols. There is an understanding that safe cancer care requires an extraordinarily high level of communication, coordination, and vigilance, with a strong focus on being aware of and acting on the incidence of errors (Gandhi et al., 2005). Authority to prescribe cancer chemotherapy is reserved for attending staff, and dosages must be expressed only in terms of daily dose. Computer system warnings prevent physicians from placing drug orders that exceed the safe maximum, and the computerized provider order entry system is extensively supported by online protocols and templates. Alerts such as a red. WARNING: HIGH CHEMOTHERAPY DOSE appear on the screen. To override the computer and exceed current guidelines, doctors must show the pharmacist new scientific results that prove a higher dose may be safe and effective. Much has been done to encourage independent checks of prescribed doses by nurses and pharmacists, and staff have been explicitly authorized to question openly any presumed dosing error. The organization describes the key lessons learned in the 10 years since Betsy's overdose as the importance of the engagement of governance and leadership, vigilance by all every day, support for victims of errors, system support for safe practice, interdisciplinary practice, and patient-and family-centered care (Conway et al., 2006; Conway and Weingart, 2005).

organizational commitment to safety, high levels of redundancy in personnel and safety measures, and a strong organizational culture for continuous learning and willingness to change (Roberts, 1990; Roberts and Bea, 2001). Although medication delivery errors may still occur, systems can be designed to be safer. Safety does not reside in a person, device or department, but emerges from the interactions of components of a system. Safety is more than just the absence of errors (IOM, 1999).

[1] Source: IOM, 2006.

Rates of Medication Errors

Recently, medication related errors became so common in hospitals that the hospitalized patients could expect to suffer at least one everyday (IOM, 2006). Some of the most common medication errors are presented in Figure 2.

Figure 2. Examples of Common Medication Errors[2]

Prescribing Phase		
Area	Cause	Effect
Patient Information	Incomplete clinical information on current status of a patient.	Decision made to treat patient with medication resulting in negative side effects.
Ordering Phase		
Drug Information	Insufficient drug information.	Misjudgment in determining units/kg dose for patient.
Drug Dispensing Phase		
Labeling and Packaging	Lack of unit dose system for dispensing medications.	Dispensed two full syringes of drug labeled "1,200,000 units" and "1,500,000 units" instead of "1.2 million units" and "1.5 million units" with "note dosage strength".
Drug Administration Phase		
Competency	Hospital has an unclear definition of prescriptive authority for non-physicians.	Nurse practitioner assumed authority to change route of administration based on national protocol and current practice in hospital.

Reason (1990) defines an error as the failure of a planned sequence of mental or physical activities to achieve its intended outcome when these failures cannot be attributed to chance. Moreover, Reason (1994) differentiates between slips or lapses and mistakes. A slip or lapse occurs when the action conducted is not what was intended. This is also often called error of execution. The difference between a slip and a lapse is

[2] Source: IOM, 2006.

that a slip is observable and a lapse is not. For example, in medicine, a slip might be involved if the physician chooses an appropriate medication, writes 10 mg when the intention was to write 1 mg. The original intention was correct (the correct medication was chosen given the patient's condition), but the action did not proceed as planned. On the other hand, a mistake in medicine might involve selecting the wrong drug because the diagnosis is wrong. In this case, the situation was incorrectly assessed and the action planned was wrong. Moreover, in considering how humans contribute to medication error, it is important to distinguish between active and latent errors (Reason, 1994). Active errors occur at the level of frontline operators, and their effects are felt almost immediately. This is sometimes called the sharp end error (Cook et al., 1998). Latent errors tend to be removed from the direct control of the operator and include things such as poor system design, bad management decisions, and poorly structured organizations. These are also often described as blunt end errors (Cook et al., 1998). For example, the active error is when the pilot crashed the plane. The latent error is that a previously undiscovered design malfunction caused the plane to roll unexpectedly in a way the pilot could not control and the plane crashed. Latent errors can be difficult for the people working within health care systems to notice since the medication errors may be hidden in the design of processes or in the structure or management of the organization. From the field studies at CH, the author also noticed that people become accustomed to design defects and learn to work around them, so the defects are often not recognized.

Past research estimated that between 60 to 80 percent of medication errors involve human error (Perrow, 1984). Yet, more recent research and analysis concluded that the majority of medication errors do not result from individual recklessness but more

commonly by faulty systems and conditions that lead people to make mistakes or fail to prevent them (National Wholesale Druggists' Association, 1998; Phillips et al., 1998). Although a disciplinary action may be appropriate in some cases (e.g., deliberate negligence), it is usually not an effective way to prevent recurrence. For example, stocking patient-care units in hospitals with certain full-strength drugs, even though they are toxic unless diluted, have resulted in deadly mistakes (IOM, 1999). Thus, mistakes can best be prevented by designing a healthcare system at all levels to make it safer, or in other words, to make it harder for people to do something wrong and easier for them to do it right (Reason, 1994). Of course, this does not mean that individuals can be careless. People still must be vigilant and responsible for their actions. Nevertheless, when an error occurs, blaming an individual does little to make the system safer and prevent someone else from committing the same error (Agenda for Research and Development in Patient Safety, 1999).

Medication errors in hospital settings occur at every step in the medication use process, however most frequently during the prescribing and administration steps (IOM, 2006). Figure 3 presents the general five steps of medication delivery system in hospital setting:

1) Medication prescribing by physician, nurse practitioner, and/or pharmacist. This step usually involves clinical decision making, drug choice, drug regimen determination, medical record documentation and medication order prescribing.
2) Medication transcribing involving checking medication prescription on the Medication Administration Record (MAR) for correctness by nurse, pharmacist and unit clerk with a supervision (co-signature) of registered nurse or pharmacist.

3) Medication preparing and dispensing by pharmacist. This step usually requires medication data entry and screening, preparing, mixing, compounding, followed by a second check and dispensing to the unit.
4) Medication administering by nurse. This step usually consists of drug preparation for administration, order-patient verification, drug administration, and finally MAR documentation. This step requires the nurses to follow the five rights ("5Rs") of medication delivery system (right patient, right medication, right dose, right route, and right time).
5) Medication monitoring including therapeutic effects and adverse drug events (ADEs), review of laboratory results if necessary, treatment of ADEs and MAR documentation.

Figure 3. Medication Use System Structure

According to different definitions of errors and methods of error identification, prescribing errors were found to occur at the rate of 12.3 to 1,400 per 1,000 patient admissions (Bates et al., 1995a,b; Lesar et al., 1997; Lesar, 2002; LaPointe and Jollis, 2003; Winterstein et al., 2004), or at the rate of 0.6 to 53 per 1,000 orders (Lesar et al., 1990; Bates et al., 1995a; Lesar et al., 1997; Lesar, 2002). In the studies that evaluated prescribing errors per opportunity for error, the rate of 1.5 to 9.9 per 100 opportunities were found (Dean et al., 1995; Lisby et al., 2005). However, the error rates depend on the thoroughness of error detection methods that are used (Gandhi et al., 2000). Most of the

above studies used less comprehensive error detection methods such as: spontaneous reporting by pharmacists after review of written orders (Lesar et al., 1997; Lesar, 2002), prompted reporting (Winterstein et al., 2004), and reporting by a clinical pharmacist participating in patient care (LaPointe and Jollis, 2003). The study (Bates et al., 1995a) that found the highest error rate by far used a more comprehensive detection method such as: chart review including review of written medication orders by a dedicated trained reviewer, in addition to prompted reporting from nurses and pharmacists. This study found a rate of 1,400 prescribing errors per 1000 patient admissions or 0.3 prescribing errors per patient per day. Of the errors identified, 7.5 percent were categorized as preventable ADEs or potential ADEs. By comparing a study (Kaushal et al., 2001) using similar error detection methods in pediatric units identified 405 prescribing errors per 1000 patient admissions or 0.1 prescribing errors per patient per day. In this study, 19.5 percent of the errors were categorized as preventable ADEs or potential ADEs.

The rates of transcribing and dispensing errors are not as comprehensively reviewed in literature as prescribing and administrating errors. The transcribing errors are most often associated with noisy and interruptive environments at hospitals and account for 3 to 7 percent of all medication errors (Cohen, 2000; IOM, 2001). One study showed that distractions are responsible for almost three quarters of all transcribing errors (Leape, 1995). Minimize these distractions creatively (i.e., overlapping coverage during peak times, division of job responsibilities, etc.) can help staff remain focused on order transcription (Cohen, 2000). The most common types of dispensing errors or near misses appeared to be incorrect strength of medication, followed by incorrect drug, incorrect quantity, incorrect dosage form and incorrect label. Research shows that dispensing

errors account for an estimated 6 to 12 percent of all medication errors (Buchanan et al., 1991; Allan et al., 1995; Flynn et al., 2003). The main causes of dispensing errors are issues concerning workload and staffing, distractions during processing, suboptimal packaging and labeling, poorly designed work areas, and outdated or incorrect drug reference information (Buchanan et al., 1991; Allan et al., 1995; Cohen, 2000; Flynn et al., 2003). A study by Chua and colleagues (2003) at community pharmacies reported that that near misses occurred six times more often than dispensing errors, indicating the importance of final checking in pharmacies. Out of a total of 51,357 items dispensed during the study, 39 dispensing errors (0.08%) and 247 near misses (0.48%) were detected.

Finally, according to several international studies, administration errors (excluding wrong time errors) are frequent with the error rate ranging from 2.4 to 11.1 percent per dose (Dean et al., 1995; Taxis et al., 2003; Barker et al., 2002; Tissot et al., 2003; Lisby et al., 2005). The U.S. study in this group found an administration error rate of 11 percent excluding wrong time errors (Barker et al., 2002). This study used an observation-based medication administration error detection method and it was carried out in 36 different facilities. For these 36 facilities, the administration error rate (excluding wrong time errors) ranged from 0 to 26 percent with 8.3 percent as the median value. A study in five intensive care units (ICU) in U.S. tertiary teaching facilities (Calabrese et al., 2001) found an administration error of 3.3 percent lower than the Barker et al. (2002) study. The ICU study identified administration errors for a group of high-alert medications using a similar observational technique. This study commented that the results were lower than the comparable French ICU study (Tissot et al., 2003)

and suggested that the difference might be due to varying methods of observation and pharmacist participation in patient care in the U.S. study. IOM (2006) believes that these results, while the best available for large intensive care units in the U.S. are not generalizable to non-ICU hospital care and that the study by Barker et al. (2002) represents the best estimate of administration error rates in the U.S. hospitals for non-ICU care. Much higher rates of administration errors were observed in two studies that focused on intravenous medications: 34 percent in a joint U.K./German study (Wirtz et al., 2003) and 49 percent in a U.K. study (Taxis and Barber, 2003). On the basis of the Barker et al. (2002) study and assuming a patient in the hospital receives 10 doses per day, a typical patient would be subject to one administration medication error per day. These data taken together with the studies which identified up to 0.3 prescribing errors per patient per day (Bates et al., 1995a) plus the fact that medication errors occur in other stages of the medication use process, for example, errors in the prescribing and administration stages accounted for 77 percent of medication errors (Leape et al., 1995), suggest that about one medication error occurs per patient per day in hospital care (IOM, 2006).

Reporting and Monitoring of Medication Errors

All healthcare provider groups should seek to be high-reliability organizations preoccupied with the possibility of failure (Reason, 1994). The IOM (2006) encourages all healthcare organizations to implement active internal monitoring programs so that progress toward improved medication safety can be accurately demonstrated. Currently, most healthcare organizations monitor medication errors by tracking voluntary reported errors (IOM, 2006). However, research shows that voluntary internal reporting systems

have recognized limitations for evaluating the true frequency of medication errors and ADEs (Allan and Barker, 1990; Cullen et al., 1995; Jha et al., 1998; Flynn et al., 2002). Jha et al. (1998) estimated that only 4 percent of medication errors are reported via voluntary reporting systems. Voluntary reporting rates are generally low because of factors such as time pressure, fear of punishment, and lack of a perceived benefit (Cullen et al., 1995). Improvements in internal reporting have been achieved in non-punitive reporting environments (Rozich and Resar, 2001), but these rates still vastly underestimate the true rate. A large study in 36 health care facilities comparing direct observation and voluntary reporting found that direct observation detected the greatest number of errors (Flynn et al., 2002). The authors concluded that the advantage of observation over voluntary reporting is that it does not rely on the heathcare provider being aware of the error (providers typically do not realize they have made an error, and if they do, they may be reluctant to report it). To keep observations economical, they also concluded that observations are best conducted for a limited number of settings in a periodic fashion. For example, they suggested 100 observations per nursing unit over a day or two to see if there is an error problem and over 1000 observations for the evaluation of technology effects on error.

Research also showed that automated surveillance and chart review could detect ADEs at a much higher rate than voluntary reporting. A comparison of automated surveillance, chart review and voluntary reporting found that of the 617 ADEs detected, chart review identified 65 percent, automated surveillance 45 percent and voluntary reporting 4 percent (Jha et al., 1998). Chart review for identifying medication errors involves looking for events in patient documentation that indicate a medication error may

have occurred, for example, a change in mental status, a new rash or diarrhea, or orders for antidotes. Chart review is an effective way of finding medication errors and ADEs, but is costly to perform and requires special training for chart reviewers. Computerized detection of ADEs is based on the use of screening criteria for triggering events. Techniques used by such systems include examining medication orders for antidotes (to indicate a wrong dose or wrong drug) and screening clinical laboratory data for results that exceed critical values. These techniques may be employed at various levels of sophistication (Bates and Gawande, 2002). Once a potential ADE has been identified, clinical review is necessary to confirm whether it was in fact such an event.

Nevertheless, voluntary reports, while not appropriate for measuring the actual frequency of errors, are useful as a basis for root-cause analysis, for identification of error trends involving certain medications, doses, forms and routes, and for providing a stimulus for organizational change. According to IOM (2006), healthcare organizations should take a number of actions to promote successful voluntary medication error reporting. First, organizations should create a learning system whereby errors and recommended preventive measures are reported and used as a tool for learning. Second, organizations should make a commitment to learning about error problems, monitoring national trends and reports, and implementing plans designed to prevent similar errors from occurring at their site. Third, to increase the strength of the evidence that error rates are truly being reduced (or increased), additional, more robust error detection methods like observations and automated surveillance should be implemented.

Barriers for Reducing Medication Errors

The United States leads the world in medical science and technology, defining the cutting edge in most fields of clinical research, training, and practice (IOM, 2005; Mitchell et al., 2005). The U.S. based manufacturers of drugs and medical devices and equipment are considered the most innovative and competitive in the world (National Science Board, 2004). Thus, the U.S. healthcare system provides high quality, highly specialized care for some individuals, but at a very high cost. At the same time, the U.S. healthcare enterprise has devoted relatively little intellectual effort for the development of effective analysis models and strategies that could help improve or optimize the operations of healthcare systems or measure performance in terms of quality, efficiency and productivity (IOM, 2005). In summary, the literature suggested the following barriers as critical factors for effective healthcare improvement:

Educational and Training Barriers

Research has criticized the insufficient education and training because usually only managerial and support personnel who are part of an established improvement team receive it (American Association of Colleges of Nursing, 1998; Human Resources and Services Administration, 2000; Huq and Martin, 2000; McFadden et al., 2004, 2006a,b). Research suggests that it is needed to increase knowledge of the philosophy and principles of continuous improvement and interpersonal skills to improve problem-solving abilities at all levels of organization (Huq and Martin, 2000; McFadden, 2006a). Despite frequent recommendations to increase emphasis on medication safety, little research effort has been devoted specifically to ‘systems thinking’ to improve or optimize the operations of medication delivery systems in terms of patient safety and systems

efficiency and productivity (American Association of Colleges of Nursing, 1998; Human Resources and Services Administration, 2000). Timothy Flaherty, MD, Chairman of the Board of the National Patient Safety Foundation (NPSF), commented that healthcare education is an area in which patient safety has seen no dramatic improvements (NPSF, 2004). As a result, very few administrators, managers, nurses or technicians are equipped to analytically view their medication delivery processes as a system, nor appreciate the relevance and benefits of systems engineering approach for systems improvement (IOM, 2005). Efforts to boost medication delivery will fail unless acute nurses and other key staff are involved from the beginning in the improvements efforts (Nursing Management Brief Report, 2007a). A survey of the U.S. pharmacy schools found that the quality and quantity of instruction about medication errors varied significantly, and that key domains of knowledge were lacking in some programs (Johnson et al., 2002). A joint report of American Health Information Management Association (AHIMA) and American Medical Informatics Association (AMIA) has pointed out that no systematic plan exists for training the current healthcare workforce to use information technology tools to do their jobs regarding the use of information technology systems to improve medication safety (AHIMA and AMIA, 2006). This report called on the healthcare industry to educate its employees at all levels that information technology is an integral part of healthcare work. To address such challenges, the following initiatives have been developed and deployed: 1) AMIA (2005) announced its 10 by 10 program, which aims to realize a goal of training 10,000 health care professionals, especially in applied clinical informatics by the year 2010; 2) Faculty Leadership in Interprofessional Education created a patient safety oriented curriculum for training the health profession faculty

leaders (Mitchell et al., 2005); 3) Creighton University has an interprofessional patient safety course available for students in business, law, social work, medicine, pharmacy, physical therapy, occupational therapy, nursing, and dentistry (Creighton University, 2005); 4) The British Pharmacological Society's Clinical Section Committee has developed a core curriculum for teaching safe and effective prescribing in the U.K. medical schools (Maxwell and Walley, 2003); 5) With the help of a grant from Agency for Healthcare Research and Quality (AHRQ), a continuing education curriculum in ambulatory care aimed at advancing patient safety and incorporating a medication errors module was developed (Mottur-Pilson, 2005); 6) The University of Wisconsin-Madison Center, with a funding from AHRQ, has developed a graduate certificate in patient safety; 7) Through a grant from AHRQ, the Medical College of Wisconsin and NPSF developed the web-based educational patient safety materials for physicians, nurses and patients (Hendee et al., 2005).

Vigilance and Compliance Barriers

Researchers found vigilance and compliance to be strongly associated with effective medication error detection and improvement efforts (IOM, 2006). Studies of organizations with a strong track record of high reliability and safety have shown that vigilance by frontline workers is essential for detecting threats to safety before they actually become errors and/or adverse events (Roberts, 1990; Roberts and Bea, 2001; Aiken et al., 2002; Needleman et al., 2002). There is support in the literature for the premise that individual's cognition mediates antecedent conditions and behavior, in general (Bem, 1981; Nelson, 198; 1Argyris, 1993; Eagly and Chaiken, 1998;). Reason (2004), a leading researcher in organizational safety advises nurses and doctors to us their

mental skills to analyze, detect and prevent errors. Researchers also suggested that healthcare professionals use cognition as a personal mediator through which the reword system and/or group-behavior influence motivation for improvement efforts (Tucker and Edmondson, 2002).

Productivity and Efficiency Barriers

Researchers indicated increasing pressures on nurses with respect to efficiency requirements (Tucker and Edmondson, 2002; Needleman et al., 2002; IOM, 2005). Organizational models and group norms where workers do not have time to resolve underlying causes of problems that arise in daily activities seems to dominate in healthcare industry (Tucker and Edmondson, 2002; Uribe et al., 2002; IOM, 2005). Recent research shows that a large proportion of nurse's time is spent on delivering and retrieving food trays, performing housekeeping duties, transporting patients, and ordering, coordinating, or performing ancillary services (Aiken and Patrician., 2000; Aiken et al., 2001; Aiken et al., 2002). Hillsden and Fenton (2006) estimated that 35% of the total nurse's time during medication administration is spent dealing with interruptions. A total of 28 interruptions were recorded across five medication rounds, with 15 (54%) being classified as 'unavoidable' and 13 (46%) being rated as 'avoidable'. Consequently, it should not be a huge surprise that nurses and pharmacy technicians are hardly able to keep up with the required responsibilities and are in essence forced to quickly patch problems so they can complete their immediate responsibilities. The document, Productivity and the Nursing Workforce, says that managers should focus on increasing work rates by releasing staff from inappropriate or wasteful activities (Nursing Management Brief Report, 2007a). Next, researchers shown that autonomy has been

linked to higher nurse satisfaction/productivity and therefore higher improvement efforts (Havens and Aiken, 1999; Scott et al., 1999; Whitley and Putzier, 1994; Aiken and Patrician, 2000) because it promotes self-management which accordingly increases worker motivation by empowering them to make decisions that affect their productivity (Campion et al., 1993; Hackman, 1987; Janz et al., 1997). Autonomy can be defined as the amount of job-related independence, initiative, and freedom either permitted or required in daily work activities (Slavitt et al., 1978).

Managerial Barriers

According to a recent survey conducted by 'YouGov', the organization that works with companies to improve performance, more than half of healthcare professionals reporting that their bosses are poor leaders and decision makers (Nursing Management Brief Report, 2007b). A total of 64 percent of healthcare employees said incompetence and lack of confidence were contributory factors to reduced productivity and low motivation for improvement. Tucker and Edmonson (2002), one of the leading researchers in the field of healthcare process improvement, suggested that nurses are likely to engage in improvement efforts if managers are physically present on the nursing floor, have a reputation for "safety" and "improvement" and have the time needed to devote to such efforts. Such managerial presence and support often can increase the feeling of "gratification" and at the same time prevent the feelings of "burnout" in frontline healthcare professionals. The report of *Productivity and the Nursing Workforce* points out that improvements are more likely to occur where there is strong leadership, and where there is feedback of information to staff, commissioners and patients (Nursing Management Brief Report, 2007a).

Organizational and Cultural Barriers

Research shows that cultural, organizational, and policy-related factors have contributed to rigid divisions of labor in many areas of healthcare, especially between nursing and management as well as nursing and physicians, negatively affecting healthcare innovations and improvements (Christensen et al., 2000; Weingart and Page, 2003). A comprehensive review of research papers published predominantly since 1990 examining the relationship between organizational context, structures, systems design and management strategies (including aspects of process, technology and human factors) and patient mortality/adverse events revealed that nursing surveillance, quality of working environment, and quality of interaction were three organizational process variables consistently related to lower mortality (Mitchell and Shortell, 1997; IOM 2005, 2006). Weingart and Page (2003), based on the conclusions from Minnesota Executive Sessions on Patient Safety (Weingart et al., 2003), highlighted that little is known about how to implement effective organizational and/or managerial structures/systems that could produce the necessary changes in healthcare industry. Ramanujam and Rosseua (2006) suggested that the desired changes can be potentially achieved via dedicated organizational structures for patient safety that promote data collection and analysis, employee feedback and continuous support for redesign/improvements. They further suggest the teamwork with explicit goals, shared vision and trust, and expanded competencies of managers and staff as curtail factors for organizational improvement (Ramanujam and Rousseau, 2006). McFadden and colleagues (2006a) tested the following seven improvements strategies proposed by Agency for Healthcare Research and Quality (partnership with stakeholders, reporting errors free of blame, open discussion of errors, cultural shift, education and training, statistical analysis of data, and

system redesign) and found that hospitals should make creating a cultural shift toward patient safety a top priority. The second highest priority should involve developing a partnership with all stakeholders, followed by creating a reporting system free of blame. Additionally, McFadden and colleagues (2006b) showed that lack of top management support, lack of resources, lack of incentives and lack of knowledge can significantly hinder the implementation of improvement strategies. A computer simulation model (Anderson et al., 2006) that has been developed to explore organizational changes required to improve patient safety based on a medication error reporting system predicted that the number of medication errors reported by hospital staff would increase over time. The simulation model also found that organizational actions needed to reduce the risks of future errors occurred less than 46% of the time and found that 96% of the actions taken in response to reported errors involved individual staff. However, organizational actions that only affect individual staff are likely to have little effect in reducing future errors (Anderson et al., 2006). Organizational or system changes could result in sustaining changes in the organization culture and practices if implemented properly (Anderson et al., 2006).

Communication and Psychological Safety Barriers

Edmondson (1999) showed that psychological safety enables willingness to engage in "second-order problem solving" behavior because improvement efforts are inherently risky and can have negative consequences for the person who raises the concerns. In addition, being associated with problems and change efforts can result in damage to one's reputation (Dutton, 1993). Therefore, workers will be more likely to engage in improvement efforts if they feel they have some protection from such backlash

(Edmondson, 1999). Nembharth and Edmondson (2006) showed that leader inclusiveness - words and actions exhibited by leaders that invite and appreciate others' contributions - can help healthcare people and teams overcome the inhibiting effects of psychological safety, allowing members to collaborate in process improvement. Ghosh and Sobek, (2007c) showed that "second-order problem solving" behavior can be enhanced via communication to the person or department responsible for the problem, bringing it to managers' attention, sharing ideas about what caused the situation and how to prevent recurrence with someone in a position to implement changes and/or verify that changes have the desired effect. Ghosh and Sobek (2007c) also proposed three characteristics for effective "second-order" problem solving: 1) need for validation of current system knowledge against reality; 2) need for joint problem solving by affected parties; and 3) need for joint validation of new knowledge. Such characteristics have been detected in hospitals that utilized "clinical microsystems" for organizational learning and delivery of care (Mohr, et al., 2004). McFadden and colleagues (2004) building on their experience in aviation safety research indicated the "open-ended focus groups" as one of the critical factors for successfully managing and controlling hospital errors.

Information Technology Barriers

Although information collection, processing, communication and management are at the heart of healthcare delivery, and considerable evidence links the use of clinical information technologies to improvements in the quality, safety, and patient-centeredness of care, the healthcare sector remains woefully underinvested in these technologies (Casalino et al., 2003). In transportation, financial services, communications, and manufacturing industries, modern information systems have enabled and hastened the

development of new high-quality products and services and the management of increasingly dispersed and complex production systems. General Motors, Wal-Mart and Boeing, just to mention a few, could not operate their organizations in today's competitive environment without the benefit of comprehensive information/ communication systems and the extensive use of engineering tools for the design, analysis, and control of complex production/distribution systems (IOM, 2005). It is reasonable to suggest that the use of information technologies could lead to higher productivity, better quality care, and improved patient safety and satisfaction, because similar business processes can be found in healthcare systems.

Information technology has to be recognized as a "member" of the healthcare system. In this context, technology does not involve just computers and equipment but also techniques and procedures used by healthcare professionals in delivering care to individuals. Thus, research on human-factors should be greatly applied to healthcare (Leape, 2004). Human-factors is defined as the study of the interrelationships between humans, the tools they use, and the environment in which they live and work. It is often used to understand where and why systems or processes break down. Such approach can help examine the processes of medication errors, looking at the causes, circumstances, conditions, associated procedures and devices and other factors connected with the event. As a result, this might lead to simplification and standardization of procedures, building in redundancy to provide backup and opportunities for recovery, improving communications and coordination within teams, or redesigning equipment to improve the human-machine interface (Reason, 1990; Leape, 1994; Evans et al., 1998; Bates et al., 1999). Two approaches have typically been used in human-factors analysis. The first is

critical incident analysis. Critical incident analysis examines a significant or pivotal occurrence to understand where the system broke down, why the incident occurred, and the circumstances surrounding the incident (Cooper et al., 1978). Analyzing critical incidents, whether or not the event actually leads to a bad outcome, provides an understanding of the conditions that produced an actual error or the risk of error and contributing factors. Another approach is referred to as naturalistic decision making (Klein, 1998). This approach examines the way people make decisions in their natural work settings. It considers all of the factors that are typically controlled for in a laboratory-type evaluation, such as time pressure, noise and other distractions, insufficient information, and competing goals. In this method, the researcher goes out with workers in various fields, such as firefighters or nurses, observes them in practice, and then walks them through to reconstruct various incidents. The analysis uncovers the factors weighed and the processes used in making decisions when faced with ambiguous information under time pressure. Numerous partnerships between human-factors engineers and the medical profession have already led to improvements in patient safety (Johnson, 2002; Nemeth et al., 2004; Xiao and Mackenzie, 2004).

Strategies and Methods for Reducing Medication Errors

Six Aims for Improvement

To cross the quality chasm in the 21st century's healthcare industry, organizations will need to successfully pass the following six major challenges (IOM, 2001). The first is to redesign care processes to serve more effectively over time. A number of well-understood design principles, drawn from other industries as well as some of today's health care organizations, could help greatly in improving the care that is provided to

patients. The second challenge is to make effective use of information technologies to automate clinical information and make it readily accessible to patients and all members of the care team. An improved information infrastructure is needed to establish effective and timely communication among clinicians and between patients and clinicians. The third challenge is to manage the growing knowledge base and ensure that all those in the healthcare workforce have the skills they need. Making use of new knowledge requires that health professionals develop new skills or assume new roles. It requires that they use new tools to access and apply the expanding knowledge base. The fourth challenge for organizations is to coordinate the care across patient conditions, services, and settings over time. Excellent information technologies and well-thought-out and implemented modes of ongoing communication can reduce the need to craft laborious, case-by-case strategies for coordinating patient care. The fifth challenge is to continually advance the effectiveness of teams. Team practice is common, but the training of healthcare professionals is typically isolated by discipline. Making the necessary changes in roles to improve the work of teams is often slowed or stymied by institutional, labor, and financial structures, and by law and custom. Cohesive healthcare improvement teams should possess five key characteristics (Grumbach and Bodenheimer, 2004): 1) clear goals with measurable outcomes; 2) clinical and administrative systems knowledge; 3) clear role definitions; 4) expertise and experience; and 5) effective communication skills. Finally, all organizations, whether or not healthcare related, can improve their performance only by incorporating care processes and outcome measures into their daily work, which is the sixth challenge. The use of such measures makes it possible to understand the degree to which performance is consistent with best practices, and the

extent to which patients are being helped. Patients themselves also could provide a major safety check in most hospitals, clinics and practice. They should know which medications they are taking, their appearance and their side effects, and they should notify their doctors of medication discrepancies and the occurrence of side effects (IOM, 1999; Agenda for Research and Development in Patient Safety, 1999).

Systems Engineering Methods and Tools

Patient safety emerges from systems that are skillfully designed to prevent harm (Cook et al., 1998). Therefore, the application of systems engineering methods and tools to the design of medication delivery processes can greatly help improve patient safety. A very good example of applying engineering concepts is the *20/80* principle or rule, which can be stated as: *design for the usual, but recognize and plan for the unusual.* Process design should be explicit for typical cases - for 80 percent of the work. For the remaining 20 percent, contingency plans should be assembled as needed. This principle is useful for both designing a healthcare system and acculturating new trainees. Also referred to as the Pareto principle, the 20/80 rule is based on the recognition that a small number of causes (20 percent) are responsible for a large percentage (80 percent) of an effect. In health care, for example, 20 percent of patients in a defined population may account for 80 percent of work and incur 80 percent of the costs. Similarly, 20 percent (or fewer) of common diagnoses may account for 80 percent of patients' health problems.

Systems (or cognitive) engineering analysis has tremendous potential to impact some of the most difficult aspects of complex systems (Dugger et al., 1999; Perry et al., 1999; Roth et al., 2001). In fact, it has been commented that the only way to deal with the increased complexities in the health care industry (including the vast amount of available

data, the pressure to make timely decisions utilizing the totality of that data, and the reduced manpower and cost goals) is to follow the steps of systems engineering analysis (IOM, 2005). Many of systems engineering applications are directly aimed at reducing cost via improving coordination between human-human and human-technology collaborations (Roth et al., 2001). The key strategies in systems engineering analysis are as follows:

1) Identify leverage points: In any optimization effort, leverage points may be places where systems "bottlenecks" exist (Militello et al., 1998).
2) Iterate: The characteristic of successful re-engineering is iteration. Changes made to a system may accidentally eliminate or create functions that influence the system. These unintended consequences can only be exposed through iteration and testing (Militello et al., 1998).
3) Address training requirements: Training is vital for systems that want to operate at its optimum. Since the human-human and human-technology collaborations play a key role, the training of individuals is of particular relevance. Individuals must know what to do and when, they must know when and how to compensate for their teammates, they must know which materials and information to provide teammates, and they must know how to fulfill responsibilities and manage resources without prompting by other members (Blickensderfer et al., 2000).
4) Address technologies that best support the optimization goals: Technologies that allow people to maintain, update, and communicate the big picture foster enhanced team communication and reduce bottlenecks that result from different team members having different interpretations of the current situation (Militello et al., 1998).

5) Design for building common ground across multiple agents: Not only is it important for team members to have a consistent model of the world and a common ground, it is also necessary for people and automated systems to share that same common ground (Woods, 2001). In human-human collaboration, common ground depends on the accuracy of assumptions between team members regarding goals, knowledge states, workload, and priorities (Klein et al., 2000). Common ground is something that must be maintained and calibrated as situations emerge. When common ground is lost in a time-critical situation, there may simply not be enough time to re-establish it. Researchers found that technologies that allowed team members to monitor the stance of others, including things such as their workload, fatigue level, and focus of attention, were most effective in sustaining common ground (Klein et al., 2000).
6) Create integrated rather than system-oriented displays: System-oriented displays are those in which the states of variables within the system are displayed. Integrated displays are those in which states of system variables are combined and presented in a manner that is congruent with the decision making goals of the operator. Therefore, integrated displays allow for rapid situation assessment (Dugger et al., 1999).

Systems engineering methods/tools have been used in many applications to achieve major improvements in the quality, efficiency, safety, and/or customer-centered processes, products, and services in a wide range of manufacturing and service industries (IOM, 2005). For example, concurrent engineering principles can be used as a team building approach, enabling employees from different functional units/departments in the hospital to communicate and to work together more efficiently (Chen and Lin, 2002, 2004, 2004). Statistical process control and control charts can help determine and

maintain the optimal status of time, cost and quality for different variables in health care delivery processes. Human-factors engineering can help the hospital on how to better integrate human elements into systems analysis, modeling, and design (Klein and Isaacson, 2003; Klein and Meininger, 2004). However, the healthcare sector as a whole has been very slow to embrace these systems engineering tools, even though they have shown to yield valuable returns to the small but growing number of healthcare organizations and clinicians that have applied them (Feistritzer and Keck, 2000; Fone et al., 2003; Leatherman et al., 2003; Murray and Berwick, 2003).

Despite an ambitious and well-defined agenda to cross the quality gaps by IOM (2001), there has been little direct interaction between the engineering and healthcare communities in the development of systems engineering methods, tools and performance measures for medication delivery improvement. The widespread uses of systems engineering tools will require determined effort on the part of healthcare providers and the engineering community.

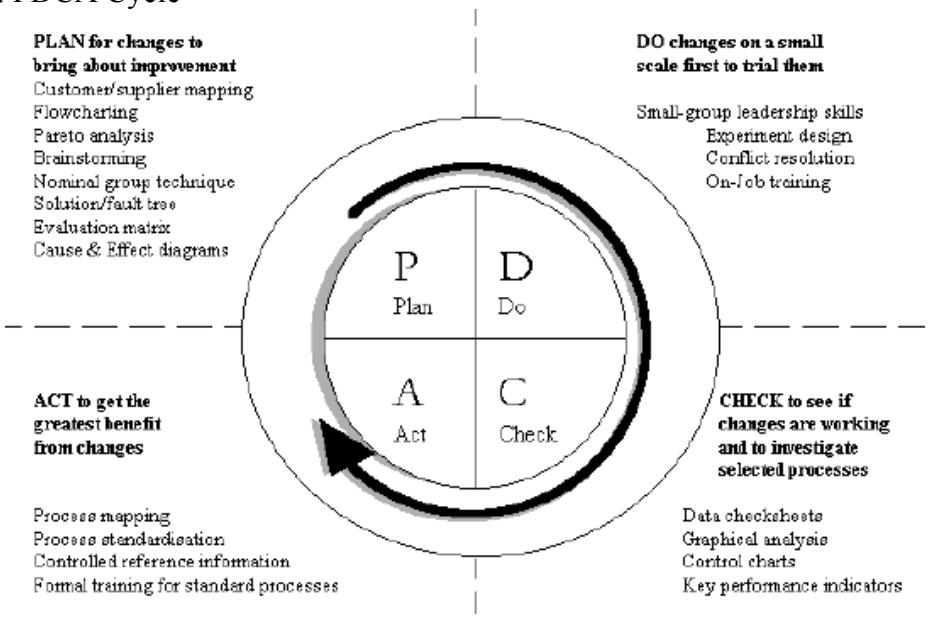
Metaroutines for Systems Improvement

A metaroutine is described as a standardized problem solving procedure for changing existing routines and for creating the new ones (Adler et al., 1999). For a metaroutine to promote root-cause problem solving (or "second-order problem solving"), it needs to capture certain elements: communication, shared investigation, and experimentation (Tucker and Edmondson, 2002, 2003; Gosh and Sobek, 2007c). Adler et al.'s (1999) empirical study in New United Motor Manufacturing Incorporation (NUMMI) finds that the workers achieved high efficiency in their day-to-day work and yet were very creative in improving routines collaboratively using standardized problem

solving procedures. Though metaroutines may inhibit innovation by systematizing the creative process, Tyre et al. (1995) find from their field study in a manufacturing environment that organizational members achieved better quality and robust solutions using a systematic approach compared to intuitive approaches.

In an effort to improve the internal work processes, healthcare organizations, over the years, have adopted various systems improvement metaroutines such as Total Quality Management (TQM), Six Sigma (SS) and Toyota Production System (TPS) to reduce high costs, wastes, inefficiencies and poor care. For example, TQM can be viewed as a metaroutine that integrates its tools with the philosophy via plan-do-check-act, or PDCA (shown in Figure 4), cycle (Deming, 1986). However, research literature on TQM reports that, even though TQM has been in existence for many years, in most cases, its success has been limited (Hackman and Wageman, 1995; Zbaracki, 1998; Keating et al., 1999; Rigby, 2001; Repenning and Sterman, 2002). Some scholars report that TQM over the years has gradually shifted from scientific problem solving, perhaps the most distinctive feature of TQM, to rhetoric (Hackman and Wageman, 1995; Zbaracki, 1998). In his study of 69 TQM programs in five sectors (i.e., defense, government, health care, hospitality, and manufacturing), Zbaracki (1998) reports surprisingly limited use of statistical tools and little evidence that organizational members followed the PDCA cycle in problem solving.

Figure 4. PDCA Cycle[3]



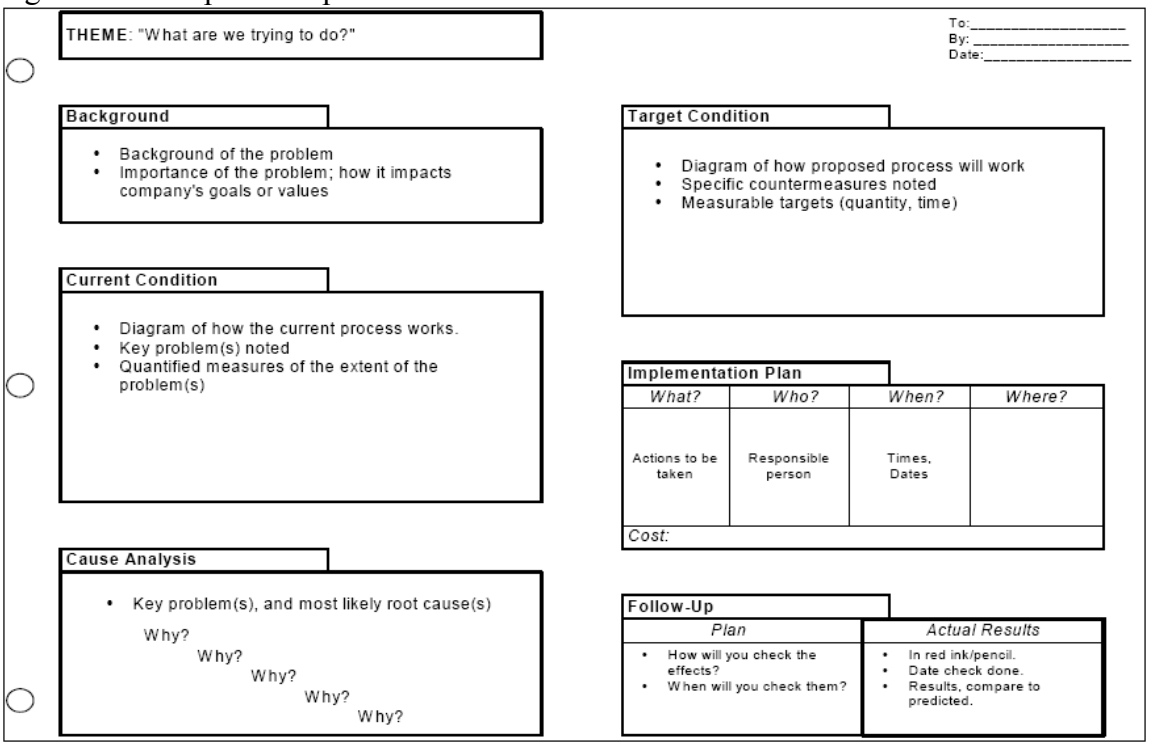
On a similar note, little empirical research on Six Sigma exists, other than the "best practice" studies by consultants or practitioners (Linderman et al., 2003), so our understanding of Six Sigma and the DMAIC (shown in Figure 5) (Define, Measure, Analyze, Improve, and Control) cycle embedded in Six Sigma metaroutine is limited. Gosh and Sobek (2007c) found that strategies such as TQM or Six Sigma when applied in healthcare settings do not prompt managers to "second-order problem solving" because they lack the objective validation of existing knowledge about current systems, which consequently leads to superficial understanding of the problem by the solvers and therefore no long-term improvements.

Figure 5. DMAIC Cycle[4]

[3] Source: http://www.hci.com.au/hcisite3/toolkit/images/pdca02.gif
[4] Graphic source: http://www.isixsigma.com/library/content/six_sigma_dmaic_quickref_define.asp

Another systems improvement strategy inspired by the PDCA has been proposed by the Toyota Cooperation. Toyota uses their improvement methods at the lowest possible level in the organization under the guidance of a teacher in conjunction with a tool, the A3 problem solving report (shown in Figure 6), which captures the key results of the major steps of the metaroutine on one side of size A3 paper (metric equivalent of 11"×17").

Figure 6. A3 Report Template[5]



The Toyota's problem solving methodology includes the following nine essential steps (Sobek and Jimmerson, 2003, 2004): 1) observing the current process; 2) drawing a diagram to represent the current process; 3) determining the root causes to the problem by asking the "5 Whys;" 4) developing the countermeasures to address the root causes to the problem; 5) drawing a diagram of the envisioned (or target) process based on consensus

[5] Graphic source: Jimmerson, et al., 2005.

with the affected parties; 6) planning the implementation; 7) discussing all of the above with the affected parties; 8) implementing the actions planned; and 9) collecting follow-up data on the outcome of the new process and comparing against pre-specified targets. Steps 1 through 7 refer to the "Plan", step 8 refers to the "Do", and step 9 refers to the "Check" stages of the PDCA cycle. The "Act" stage is the creation of new organizational work routines when they prove worthy in step 9. These nine steps provide an approximate order for solving problems.

Furthermore, Spear and Bowen (1999) discovered that Toyota's problem solving success can be directly attributed to four fundamental principles or so-called Rules-In-Use that it uses in designing or improving work processes (Gosh and Sobek, 2007a):

- Rule 1 – All work shall be highly specified as to content, sequence, timing, and outcome. Content refers to the specific tasks within an activity, sequence to the sequential order in executing the tasks, timing to the time taken by individual tasks, and outcome to the desired results from the activity.
- Rule 2 – Every customer-supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses. Spear and Bowen (1999) found that Toyota emphasizes clear and direct interactions between adjacent customers and suppliers to communicate requests for goods and services and response to such requests. Therefore, the clearest communications are binary.
- Rule 3 – The pathway for every product and service must be simple and direct. A pathway is defined as a series of connected activities that creates and delivers goods, services, and information. It is the larger set of routines that produce the organization's output. Spear and Bowen (1999) observed that the flow of goods and

services in Toyota plants follow a designated path from beginning to end, in contrast with non-TPS organizations where flows tend toward the next available resource often resulting in convoluted paths.

- Rule 4 – The fourth rule-in-use is a metaroutine for making changes to processes.

Even though TPS is widely accepted as the most efficient production system developed to date, its application outside manufacturing is limited (Thompson et al., 2003; Sobek and Jimmerson, 2003, 2004; Jimmerson et al., 2005; Spear 2005). Gosh and Sobek (2007a,b,c) examined TPS design rules and found that they may be effective in improving work processes in health care. They further tested Toyota's A3 Report for process improvement and found the A3 Report to be an objective tool that promotes joined communication and behavioral change towards a common purpose in improving organizational work processes.

Theory Building and Qualitative Methods

In common language, we often use the word 'theory' to express our observations, beliefs and/or behaviors. However, in such usage, most often a theory is not necessarily a true description of fundamental phenomena that govern the reality but represents the personal interpretation of reality. Qualitative research methods on the other hand follow a systematic approach that involve examination, analysis and interpretation of observations for the purpose of discovering underlying meanings and patterns of relationships, including classifications of types of phenomena and entities, in a manner that does not involve mathematical models (Denzin and Lincoln, 2000). In science, we further distinguish between theory and theoretical models (Lerner, 1998). Most theoretical models are constructed in order to explain and/or predict phenomena. We might think of

theory as a coherent set of interrelated models to master the phenomena. Lerner (1998) in the context of modeling human behavior stated that the important difference between theories and models is that the first is explanatory as well as descriptive, while the second is only descriptive.

There are a number of different methods to develop a theory and/or theoretical models or to explain phenomena. In the qualitative paradigm the most common strategies are:

- Phenomenology – with roots in philosophy the goal of phenomenological research is to describe the essence of behavior, based on meditative thought and with the purpose of promoting human understanding (Jarzombek, 2000). It seeks to understand the lived experience of individuals and their interactions with the world. Phenomenology does not try to develop models, theories or general explanations but it tries to describe accurately the experience of the phenomenon under study. It uses descriptive and/or interpretive writings as well as discussion to document, analyze and validate the research findings (Morce and Field, 1995).
- Ethnography - has its roots in anthropology and it is often used in social science research. It. relies heavily on up-close, personal experience and possible participation in the field study (Agar, 1996). The ethnographic research uses the culture and history of the domain under study as a "lens" to analyze/interpret the observations. Typical ethnographic research employs three kinds of data collection: interviews, observation, and documents (Fetterman, 1998). This produces three kinds of data: quotations, descriptions, and excerpts of documents, resulting in one product: narrative description. This narrative description often includes charts, diagrams and additional

artifacts that help to tell "the story" (Hammersley, 1990). Ethnographic methods can give shape to new constructs or paradigms, and new variables, for further empirical testing in the field or through traditional, quantitative social science methods (Morce and Field, 1995).

- Grounded Theory – with the roots in epistemology (Cohen, 1998; Hawthorne, 2005) it is a methodology for developing theory that is grounded in data (Strauss and Corbin, 1998). It heavily relies on "theoretical sensitivity", which refers to a personal quality of the researcher and relates to understanding the meaning of data. Since their original publication in 1967 (Glaser and Strauss, 1967), Glaser and Strauss disagreed on how to conduct the research under grounded theory. According to Kelle (2005), the controversy between Glaser and Strauss boils down to the question whether the researcher uses a well defined "coding paradigm" and always looks systematically for "causal conditions", "phenomena/context", "intervening conditions", "action strategies", and "consequences" in the data (as proposed by Strauss, 1987, Strauss and Corbin, 1998), or whether theoretical codes are employed as they emerge in the same way as substantive codes emerge, but drawing on a huge fund of "coding families" (as proposed by Glaser, 1992). Literature review suggests that novices who wish to get clear advice on how to structure data material may be satisfied with the use of the coding paradigm (Strauss and Corbin, 1998) since the paradigm consists of theoretical terms which carry only limited empirical content the risk is not very high that data are forced by its application. However, it must not be forgotten that it is linked to a certain micro-sociological perspective (Kelle, 2005). Researchers using grounded theory can collect data through interviews, observations, surveys, or

anything that comes the researcher's way while studying the topic (Glaser, 1992). The analysis of data is accomplished in three stages: 1) open coding; 2) axial coding; and 3) selective coding.

1) Open coding is the process of selecting and naming categories and subcategories from the analysis of all data. Categories involved in the phenomena are identified, labeled, categorized and related (initially) together. Two types of categories are usually used: 1) "in-vivo" categories which represent categories elicited by the participants themselves; 2) "in-vitro" categories which represent researcher's language. The properties of categories are described and dimensioned (if possible) at this stage. This involves placing or locating the property or characteristic of the category with possible range of values (i.e., high, median, low).
2) Axial coding utilizes "coding paradigm" or "coding families" to identify causal relationships between categories. The aim of the coding paradigm is to make explicit connections between categories and sub-categories. This process is often referred to as the "paradigm model" and involves explaining and understanding relationships between categories in order to understand the phenomenon to which they relate.
3) Selective coding involves the process of selecting and identifying the core category(s) and systematically relating it to other categories. It involves validating those relationships, filling in, and refining and developing those categories. Validation is done by generating hypothetical relationships between categories and using data from the field to test these hypotheses. Categories may be further

refined and reclassified and the storyline may be further refined. This completes the grounding of the theory.

- Participant-Observer – has its roots in anthropology (Darnell, 2001). It emerged as the principal approach to ethnographic research and relied on the cultivation of personal relationships with local informants as a way of learning about a culture, involving both observing and participating in the social life of a group (DeWalt and DeWalt, 2002). Participant-observer research usually involves a range of data collection methods (i.e., informal interviews, direct observation, participation in the life of the group, collective discussions, analyses of personal documents produced within the group, self-analysis, and life-histories). Thus, although the method is generally characterized as qualitative research, it can (and often does) include quantitative dimensions (Hammersly, 1990). Participant observation is usually undertaken over an extended period of time, ranging from several months to many years. An extended research time period means that the researcher will be able to obtain more detailed and accurate information about the people he/she is studying. The analysis is the summarization of large quantities of data into understandable information from which well-supported and well-argued conclusions are drawn (DeWalt and DeWalt, 2002). In general, participant-observer analysis method overlaps with the more formalized analysis used by grounded theory (Glaser and Strauss, 1967; Strauss and Corbin, 1998).

Summary of Literature Review

Sound medication delivery systems must integrate human capabilities with technologies and streamlined health care processes. After a careful literature review, the existing and critical gaps (i.e., errors rates, lack of knowledge, etc.) in medication delivery systems in hospitals were identified. Clearly, effective strategies for efficient medication delivery improvement in hospital settings are needed.

To effectively manage medication delivery systems, the processes used by healthcare professionals to report, analyze and improve medication error rates must be well understood. Cost, safety and rates of medication errors were first identified in order to gain deeper understanding of such processes. Second, the challenges and strategies to improve medication delivery systems were reviewed. Literature showed that systems engineering methods and tools as well as metaroutines for promoting the "second-order" problem solving are most successful in improving healthcare processes.

By recognizing the critical needs for medication delivery improvement and the knowledge gap in the healthcare industry, a set of strategies for work flow, managerial and education improvement for medication delivery improvement is proposed.

RESEARCH DESIGN AND METHODS

The research agenda included four parallel pathways. The first one was to enhance the understanding of what are the major factors having significant effects on medication errors in medication use systems? The second pathway was to increase the understanding of the phenomena needed to stimulate and sustain medication error reporting, analysis and improvement by the frontline healthcare professionals (i.e., nurses, pharmacists and pharmacy technicians). The third pathway was to test and evaluate an engineering method (Map to Improve ("M2I") method) (Mazur and Chen, 2007, 2008)) for medication delivery systems improvement and learn how it affects nursing students' individual and cooperative abilities to analyze and solve the medication delivery problems. The fourth pathway was to identify the skills needed for future healthcare professionals to solve medication delivery problems and determine how these skills can be developed.

The community hospital (CH) which agreed to participate in our research is a not-for-profit organization that has been active since 1896. At the time of the study, it consisted of 89 inpatient beds, over 1000 employees including more than 120 medical staff specializing in numerous fields of medicine.

Data Collection

Data Collection for Research Objectives #1 and #2

The author implemented the M2I method (Mazur and Chen, 2007, 2008) for 12 departments at CH. Departments involved were the Cath Lab, Cancer Treatment Center, Labor and Delivery (L&D), Nursing, Post Anesthesia Care Unit (PACU), Day Surgery, Emergency Department (ED), Operation Room (OR), Intensive Care Unit (ICU), Medical Floor, Surgical Floor, and Pharmacy (with five sub-systems: medication delivery, IV delivery, narcotics delivery 1, narcotics delivery 2, and purchasing). The participant-observer method based on the recommendation by Atkinson and Hammersley (1998) and DeWalt and DeWalt (2002) was used to collect qualitative and quantitative data for both objectives #1 and #2. In two years, the author spent 246 hours observing the medication delivery processes in CH. The breakdown of the observation hours for each department is summarized in Table 1. The author worked with 63 nurses, 6 pharmacy technicians, 5 pharmacists, 12 departmental managers and 5 top administrators (vice presidents of Clinical Services, Operations, and Finance; and Quality/Risk Management administrators). The composition of the observed CH nursing workforce is summarized in Table 2 by average number of years of experience and number observed.

Throughout the data collection, the author's focus was virtually limited to "listening to participants". Participants were randomly selected and instructed to verbally and freely evaluate/comment on two factors: 1) task and connection complexity; and 2) resources problems. The managers of each unit were asked to evaluate the third factor, namely the qualifications of human resources performing each task and connection. These three factors were selected based on the recommendations by leading healthcare

organizations and researchers, who suggested that improvement actions should focus on the following three areas:

1) Process Improvement: The managers should try to simplify and standardize the workflows within their systems (National Patient Safety Partnership, 1999; National Coordinating Council for Medication Error Reporting and Prevention, 2005; Sobek and Jimmerson, 2003, 2004; Spear, 2005). In general, simplifying key medication delivery processes can minimize problem solving and greatly reduce the likelihood of errors (Klein and Isaacson, 2003). The purpose of standardization should be to reduce reliance on memory and vigilance as well as to make effective use of constraints and forcing factors (IMO, 2005). It allows the newcomers who are unfamiliar with a given process or device to use it safely.
2) Use of Resources: There is considerable evidence linking the poor and effective use of resources/technology to reduce or improve quality and safety of medication delivery respectively (Classen et al., 1991; Evans et al., 1998; Garibaldi, 1998; Bates et al., 1999; Casalino, 2003; Breslow, 2005; Clayton, 2005). The managers should strive to achieve higher productivity, efficiency and improved patient safety through a more proficient use of available resources for medications and information collection, processing, communication and management.
3) Consideration of Human Factors: Any human beings do have certain intellectual strengths, such as academic knowledge, experience, large memory capacity, large repertory of responses, flexibility in applying these responses to information inputs, and ability to react creatively and effectively to the unexpected events (IOM, 2005). Human beings also have limitations including difficulty in attending

carefully to multiple things at once, difficulty in recalling detailed information quickly, and generally poor computational ability (IOM, 2005). The literature has suggested that the qualifications of healthcare professionals (i.e., educational training, experience, personality, etc.) should be taken into account while designing work systems in which humans are expected to work (Haberstroh, 1965; Reason, 1990, 1994, 2004).

In addition, the participants self-reported and shared their feelings and views about current medication management practices and culture at CH. Notes were recorded on the instruments for task analysis and connection analysis in the 'major problems/ improvement suggestion' section of the instrument (Mazur and Chen, 2007; please see Appendix A and B for each instrument template) then rewritten in the researcher's personal journal, and crosschecked/validated by the participants for correctness using unstructured interviews and conversations. Such processes allowed the author to minimize the potential study bias (i.e., Hawthorne effect (Adair, 1984)).

Table 1. Summary of the Observation Hours for Research Objectives #1 and #2

	Department Name	Observation Hours
1	Cath-Lab	14
2	Cancer treatment Center	18
3	Labor and Delivery (L&D)	24
4	Nursing	12
5	Post Anesthesia Care Unit (PACU)	12
6	Day Surgery	18
7	Emergency Department (ED)	30
8	Operation Room (OR)	6
9	Medical Floor	8
10	Surgical Floor	8
11	Intensive Care Unit (ICU)	6
12	Pharmacy (with 5 sub-processes)	90

Table 2. Summary of the Observed Nurses for Objectives #1 and #2

	Level of Licensure	Average Number of Years of Experience	Number Observed
1	License Practitioner Nurse (LPN)	8.125	8
2	Registered Nurse (RN)	8.5	55

Data Collection for Research Objectives #3 and #4

A one-semester project, with 16 nursing students was conducted for data collection. Their work was carried out under the supervision of the author, nursing faculty, and Quality/Risk department representatives from CH. Nursing students who voluntarily participated in the study received a one-hour training session to learn how to use the M2I method to analyze the medication delivery steps. The idea behind the training session was to teach students how to use the M2I method, and not to persuade them about its potential effectiveness. The nursing students were to identify, analyze and suggest improvements for a specific problem with medication delivery at CH using the M2I method. Students were able to observe and interact with processes and other CH professionals during the three-month period of their clinical experience at CH. All inpatient departments including the Medical Floor, Intensive Care Unit (ICU), and Emergency Department (ED) were selected for the study.

During the semester, data was collected using student journals. Each nursing student used an electronic journal to document his/her activities regarding medication delivery improvements over time. The key data from the research standpoint were:

1) Date and time spent on each activity
2) Indication of individual or teamwork activity.
3) Description and rationale for each medication error reported and unreported.

4) Description and rationale of analysis steps undertaken for each reported medication error.
5) Description and rationale of decisions/improvements made for each reported medication error.
6) Description of pros and cons of any other factors (i.e., communications, teamwork, organizational or managerial support, the M2I method, etc.) involved during reporting, analysis, and improvement of medication errors.

Data was also collected through weekly focus groups led by two project supervisors (the nursing faculty and the author of this paper). The focus group sessions allowed the author to collect more in-depth data to further understand "how" and "why" that some of the steps being described or missing in their journals were accomplished. At any time during the study the students were allowed to consult with all project supervisors about encountered problems. The data was also collected by reviewing all the submitted M2I improvement reports from the students. Finally, upon completion of the project, the author conducted a survey study using the instrument presented in Figure 7. The survey study helped the author to learn how the M2I method affected nursing students' individual and collaborative abilities to analyze and solve medication delivery problems. The survey instrument contained both positively and reversed negatively worded close-ended questions. In designing the instrument, the author followed the guidelines provided by the literature (Aiman-Smith and Markham, 2004; Alreck and Settle, 2004) as well as expert advises from the Psychology Department at Montana State University. The survey instrument was kept short to maximize the rate of responses without diluting the survey objectives. The survey instrument was administered

to nursing students with a cover letter. The cover letter explained to students that this project is voluntary, and they were free to stop at any time.

Figure 7. Survey Instrument

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Based on the experience from the completed project, please asses the following bulleted items:

(Q1)_____ Organized documentation via M2I improvement tool helped me to remember information such as words, numbers, pictures, and procedures about the problem.

(Q2)_____ Organized documentation via M2I improvement tool rarely helped me to manage my efforts during the project.

(Q3)_____ Drawing system map(s) helped me to combine/arrange different pieces of information about the studied work processes.

(Q4)_____ Drawing system map(s) was unnecessary to understand the studied work processes.

(Q5)_____ Visualization of the current state helped me to organize my understanding about the root-cause(s) of the studied problem.

(Q6)_____ Visualization of the current state was not important to facilitate my understanding about the root-cause(s) of the problem.

(Q7)_____ Linking the process flow with task(s) characteristics (i.e., cycle time, batch size, human resources, and availability) helped me to recognize the true root-cause(s) of the studied problem.

(Q8)_____ Linking the process flow with task(s) characteristics (i.e., cycle time, batch size, human resources, and availability) to recognize root-cause(s) of the studied problem was a complicated and time consuming task that should be undertaken by highly trained staff in this area, rather than myself as a nurse.

(Q9)_____ Experimentation by drawing/redrawing system map(s) helped me to generate ideas to fix the root cause(s) of the studied problem.

(Q10)_____ Experimentation by drawing/redrawing system map(s) rarely helped me to ensure that my mental ideas are valid and feasible.

(Q11)_____Visual representation of the system on the map(s) facilitated the communication with others.

(Q12)_____ Communication via visual representation of the system on the map(s) was complex and difficult to follow.

(Q13)_____ Thinking via visualization of the studied system map(s) helped me to facilitate the improvement planning.

(Q14)_____ Thinking via visualization of the studied system map(s) did not prompt me to be aware of the big picture for improvement planning.

(Q15)_____ Linking the process flow with task(s) characteristics (i.e., cycle time, batch size, human resources, and availability) helped me to select the indicators to measure improvement with respect to the root-cause(s) of the studied problem.

(Q16)_____ Linking the process flow with task(s) characteristics (i.e., cycle time, batch size, human resources, and availability) distracted me from thinking about other system characteristics that were potentially important for improvement/safety assurance.

Data Analysis

Data Analysis for Research Objective #1

During and after the participant-observer studies in each department, the research team categorized all the participants' comments/evaluations with respect to three major factors:

- Technical Complexity with one category: 1) flow complexity of task/connection activities (or in other words: how easy or how hard to complete the task/connection?). This category was further analyzed based on the process characteristics used by Toyota in designing and improving work processes (Spear and Bowen, 1999): 1) content; 2) sequence, 3) timing and 4) outcome.
- Resources Problems with four categories: 1) automated resources of medication delivery (i.e., tube system); 2) manual resources of medication delivery (i.e., delivery cart); 3) automated resources of medication information delivery (i.e., computer, software, fax machine, phone, etc.); and 4) manual resources of medication information delivery (i.e., paper work).
- Qualification of Human Resources with six categories: 1) registered nurses (RN); 2) licensed practical nurses (LPN); 3) nurse aides; 4) technicians; 5) unit clerks; and 6) pharmacists.

To understand and link the sources of medication delivery errors to patient safety and systems performance, all the categorized evaluations made by the participants from 12 departments were coded by the following scales:

- Technical Evaluation (T): 0 = adequate (no action needed), 1 = adequate (adjustments needed), 2 = not adequate (changes/redesign needed).

- Resources Evaluation (R): 0 = adequate (no action needed), 1 = adequate (adjustments needed), 2 = not adequate (changes/replacement needed).
- Human Resources Evaluation (HR): 0 = qualified, 1 = over qualified, 2 = qualified (training needed), 3 = not qualified.

The above scales proposed by the author are based on his experience at CH when the participant-observer method was used. In general, it was found that the participants, when asked to comment/evaluate a task, a connection or a resource, would categorize their responses via the following three ways:

- Satisfactory (or adequate) with no further doubt. For example:

  "…this is the best piece of equipment we have in this hospital [laugh]…it saves me so much time everyday and it never breaks…"

- Satisfactory (or adequate) followed by "however", "but" or similar statement. For example:

  "…the tube system is really helpful, however when it breaks down we often need to wait three to four days to get it fixed. That is when we really need to run around the hospital to deliver meds…"

- Not satisfactory (or not adequate) with the expression of negative feeling/belief. For example:

  "…this printer is 100 years old! We need to get a new one! It breaks down all the time…"

In addition, different from Technical and Resources Evaluations, all Human Resources Evaluations were performed by the departmental managers, so that accurate data were collected.

The following are a summary of factors, categories and levels in task and connection analyses:

- In task analysis: 1) technical complexity with 1 category and 3 levels coded by 0, 1, and 2; 2) resources problems with 4 categories and 3 levels coded by 0, 1, and 2; and 3) qualification of human resources with 6 categories and 4 levels coded by 0, 1, 2 and 3.
- In connection analysis (with respect to each of three connection types: one-to-one, one-to many, and many-to-one): 1) technical complexity with 1 category and 3 levels coded by 0, 1, and 2; 2) resources problems with 4 categories and 3 levels coded by 0, 1, and 2; and 3) qualification of human resources with 6 categories and 4 levels coded by 0, 1, 2 and 3.

To analyze the coded data, the Chi-Square test for frequency counts was utilized. The Chi-Square test is often used to reflect the magnitude of discrepancies between the observed (or categorized) and expected responses. In other words, the null hypothesis (H_o) that all categories' proportions are equal is tested against the alternative hypothesis (H_a) that at least one proportion differs. Therefore, in this study the research team specifically looked for statistics suggesting the equality of proportions (or failing to reject the null hypothesis) within each of the factor. Two Chi-Square tests were performed for the factors of technical complexity and resources problems: 1) to test the null hypothesis that all frequency counts of responses coded by 0-adequate (no action needed), 1-adequate (adjustment needed), and 2-not adequate (changes/redesign needed) are equal; and 2) to test the null hypothesis that the frequency count of responses coded by 0-adequate (no action needed) is equal to the sum of responses coded by 1-adequate

(adjustment needed) and 2-not adequate (changes/redesign needed). The same two Chi-Square tests were also performed for the factor of qualification of human resources, except that the responses were coded from 0 (qualified) to 3 (not qualified). Such analysis allowed the research team to quantitatively identify the most problematic factors within the medication delivery system at CH.

Data Analysis for Research Objective #2

An iterative qualitative analysis using grounded theory methods was conducted (Strauss and Corbin, 1998). To make sure the research is trustworthy and robust the author used Wolcott's (1994) practical strategies to conduct qualitative research. The author also used contextualism and abductive inference as the logical foundation for theoretical model building, fallibilsm as a criterion for the applicability of theoretical preconceptions in qualitative inquiry, and statistical corroboration of categories as the need for the "grounding" of empirical data (Kelle, 2005). The basic principle of this approach is that a theoretical model must not emerge from empirical data alone, but it can be contextually combined with existing theoretical knowledge in a creative and justifiable way. The author believes that combining systematic data collection and data analysis of grounded theory methods with previous knowledge and unique project challenges at CH allows the research findings to be generalized for broader uses. The author also conducted statistical analysis of categorical data to strengthen the qualitative findings.

With the "real-time" data collected in the field (that is researcher's notes observed and collected during the field work on M2I instruments (Mazur and Chen, 2007), the author used the "sentence/paragraph" technique in open coding to look at the entire sentence or paragraph to generate categories (Strauss and Corbin, 1998).

To develop the theoretical model the author related the coded categories to their sub-categories using the coding paradigm technique in axial coding with the following basic steps: 1) Grouped the categories based on the answers to the questions of "why", "where", and "when". Such grouping allowed the author to form a structure of circumstances in which the phenomena under study were embedded. 2) Looked into actions/interactions which were strategic or routine responses by individuals or teams to issues, problems, happenings or any other events that aroused during those circumstances. Actions/interactions were represented by questions of "who" and "how". 3) Studied the consequences which were the outcomes of actions/interactions. Consequences provided the answers to what happened as a result of actions/interactions.

Finally, the author integrated and refined the phenomena based on the following six criteria in selective coding (Strauss and Corbin, 1998):

1) Phenomena must be 'central', that is, all identified major categories can be related to it.
2) Phenomena must be applicable (or present) to/in almost all individuals under study.
3) The phenomena must be logical and consistent with empirical data. There should be no forcing of data.
4) Phenomena must be sufficiently abstract, so that they can be used to do research in other substantive areas, leading to development of even more general theory.
5) As phenomena are integrated with other phenomena, the major the general theory should grow in depth and explanatory power.
6) The phenomena should be able to explain the variation and main point made by the data.

In general, the author justified the research findings based on four central criteria: fit, understanding, generality and control (Strauss and Corbin, 1998). Fit entails that the findings fit the empirical data. Understanding entails that the findings are comprehensible to all involved participants in the area of study. Generality entails that the findings are applicable in a variety of contexts (however under our research "umbrella", not necessary to all contexts). Control implies that the findings provide control with regard to the action toward the phenomenon/propositions.

The author validated the research findings using Guba's (1981) criteria including credibility, transferability, dependability, and confirmability. First, the author took into account potential cognitive biases (Kahneman, et al., 1982; Gilovich, et al., 2002) (i.e., bandwagon effect, blind spot, choice-supportive bias, etc). This action improved the *credibility* of the study. Second, the author included the descriptive, context-relevant statements in the results, so that readers can identify themselves with the research setting. This action helped improve the *transferability* of the study. Third, the author used triangulation for data collection (i.e., journal notes, observations, informal interviews and conversations) and had the CH staff members interpret the data to confirm the validity of the research notes and findings. This helped improve the *dependability* of the study. Finally, the author established the *confirmability* of the study by using candid approach with accurate writing and analysis (Denzin and Lincoln, 2003).

Data Analysis for Research Objectives #3 and #4

Based on author's field experience, one semester long pilot study with two nursing students utilizing M2I to solve medication delivery problems, and the literature review, the following eight predictor variables were established:

- Memorizing via organized documentation (Q1-Q2): the skill to remember information such as words, numbers, pictures, and procedures about the studied problem.
- Distilling and grouping information via drawing system map(s) (Q3-Q4): the skill to combine/arrange different pieces of information about the work processes.
- Brainstorming via visualization (Q5-Q6): the skill to organize and understand about the root-cause(s) of the problem.
- Recognizing root-cause(s) of the problem via linking the process flow with task(s) characteristics (Q7-Q8): the skill to recognize the true root-cause(s) of the problem.
- Generating creative improvement ideas via experimentation by drawing/redrawing system map(s) (Q9-Q10): the skill to generate ideas to solve the root-cause(s) of the problem.
- Communication via visual representation (Q11-Q12): the skill to facilitate the communication with others via visual representation.
- Systems thinking via visualization (Q13-Q14): the skill to facilitate the improvement planning via visual representation.
- Selecting the improvement measures via linking the process flow with task(s) characteristics (Q15-Q16): the skill to select/develop the indicators to measure improvement with respect to the root-cause(s) of the problem.

In order to analyze the responses on the identified predictor variables, the nursing students were asked to evaluate each survey question using a 5-point Likert scale (1932) (from 1 = strongly disagree to 5 = strongly agree). For each student and under each factor, the author added up the scores from positive worded close-ended questions and

reversed scores (6 minus the actual score) from reversed-negative worded close-ended questions and averaged them to get a composite score for each predictor variable.

Data analysis was completed using the evaluation of the criterion and control variables.

- Process improvement (criterion variable): process improvement (PI) is defined as the improvement in various process parameters (productivity, wasted time, number of errors, costs, and patient care) as a result of problem solving, as reported by the nursing students. The author reviewed all submitted M2I improvement reports from the nursing students at the end of the semester. Each report was assessed using a 5-point Likert scale (Very Good, Good, Average, Poor, Very Poor) based on the binary decisions (answer to questions 1 to 5: Yes = 1pt; No = 0pt) about the quality of their proposed solutions in terms of five evaluation points:

1). Was the problem clearly defined? (focus on problems not solutions!)

2). Were the objectives met based on the identified major problems? (find the causes and solve the problems, but not the effects!)

3). Were the proposed improvement actions feasible? (what needs to be done?)

4). Were the implementation plans feasible (how and when it needs to be done?)

5). Were the improvement measurement plans feasible? (how to compare the current system vs. the new system?)

Evaluation points were assigned to each student's M2I report by the author and the quality improvement professional at CH responsible for medication error reporting and improvements. Such standardized evaluation helped to control the assessment of process improvement. The final quantification was done by adding up the scores from five

evaluation points to get a composite score for the criterion variable - process improvement.

- Following the M2I process (control variable): M2I requires executing certain key steps in the problem solving process. This control variable was used to investigate the potential effect it may have on the relationship between the predictor and criterion variables in process improvement. The author assessed the control variable using a 5-point Likert scale (from 1 = strongly disagree to 5 = strongly agree) based on the binary decisions on whether following all 10 input boxes in the M2I tool shown in Figures 10 to 12 (Were M2I boxes filled? Yes = 0.25pt, No = 0pt) as well filling the boxes correctly (was the content correct? Yes = 0.25pt, No = 0pt)

To learn how M2I method affects nursing students' individual and collaborative skills to analyze and solve medication delivery problems, the multiple regression analysis was utilized. Due to the subjective nature of the data, the significance level was set at 0.10 as recommended by Garsen (2002). First, the author checked for any missing data in survey responses as well as in final project reports including the completed M2I improvement tools. Second, the author checked for outliers with respect to the criterion, predictor and control variables. Third, the linearity of each predictor variable with respect to criterion variable was checked by drawing bivariate scatter plots. Fourth, the author calculated the Cronbach's alpha for each set of questions under every testable ability in the survey. Cronbach's alpha is a reliability measure of a psychometric instrument. For this reason the Crombach's alpha is often refereed as the internal consistency of the test. Variables with Cronbach's alpha between 0.6 and 0.95 were acceptable for all testable abilities to ensure reliability (or internal consistency) of the survey questions (Robinson

et. al., 1991). Next, the author looked into the data to ensure that the correlations between variables were less than 0.75 to ensure the discriminant validity of the test (Mason and Perreault, 1991; Pelled, at el., 1999). In general, discriminant validity of the test describes the degree to which the operationalization (or the process of measuring the variable through a specific test) is not similar to (or diverges from) other operationalizations that theoretically they should not be similar to. Finally, using the software package, the author performed multiple regression analysis for the criterion variable to identify predictor variables (skills) that lead to successful problem solving. Before conducting the regression analysis, the author checked the normality assumptions of each predictor variable by drawing the normal probability plot. After creating the model, the homoscedasticity (or the homogeneity of variance) of the residuals was also checked.

RESULTS AND DISCUSSION

Results and Discussion of Research Objective #1

Table 3 shows the statistical summary for task analysis. The evidence from Table 3 suggests that null hypothesis of equal proportions is failed to be rejected only for the factor of technical complexity of tasks after categories of 1-adequate (adjustment needed) and 2-not adequate (changes/redesign needed) were combined (Chi-Sq = 0.57, p = 0.752 with *df* = 1). Specifically, the participants indicated that only 47% of tasks (82 out of 174 responses) require no improvement actions with respect to content, sequence, timing, outcome or combination of these factors. Therefore, it can be concluded that healthcare professionals suggest that technical complexity of tasks is the most problematic factor in medication delivery systems.

Table 3. Task Analysis Summary with Chi-Sq Statistics

Task Analysis Summary				
Technical Complexity	Counts	Ch-Sq	Counts	Ch-Sq
0 = adequate (no action needed)	82	17.10	82	*0.57
1 = adequate (adjustments needed)	54		92	
2 = not adequate (changes/redesign needed)	38			
Resources Problems	Counts	Ch-Sq	Counts	Ch-Sq
0 = adequate (no action needed)	123	103.24	123	23.34
1 = adequate (adjustments needed)	42		58	
2 = not adequate (changes/redesign needed)	16			
Human Resources Qualifications	Counts	Ch-Sq	Counts	Ch-Sq
0 = qualified	114	265.82	114	69.82
1 = over qualified	8		18	
2 = qualified (training needed)	8			
3 = not qualified	2			
Notes: *p > 0.1 (fail to reject the null hypothesis)				

The resources problems and qualification of human resources factors show no statistical significance with approximately 67% (123 out of 171 responses) and 86% (114 out of 132 responses) adequate responses (coded 0), respectively.

To further analyze the characteristics of technical complexity of tasks, the proportions of adequate-coded responses to resources problems in task analysis were summarized in Table 4. This direction of analysis was chosen based on participants' comments/opinions about poor training and difficulties with utilizing the available resources/technology for medication delivery[6]. The results suggest that healthcare professionals indicated category 4) manual resources of medication information delivery (i.e., paper work) as the most problematic resource in the medication delivery system (61% of adequate responses). Contrary, category 3) automated resources of medication information delivery (i.e., computer, software, fax machine, phone, etc.) was claimed by healthcare professionals to be the least problematic (82% of adequate responses).

Table 4. Task Analysis – Resources Problems

Task Analysis - Resources Problems	
0 = adequate (no action needed)	%
1) Automated resources of medication delivery (i.e., tube system)	75%
2) Manual resources of medication delivery (i.e., delivery cart)	70%
3) Automated resources of medication information delivery (i.e., computer, software, fax machine, phone, etc.)	82%
4) Manual resources of medication information delivery (i.e., paper work)	61%

Table 5 shows the statistical summary for connection analysis. The results suggest that technical complexity of many-to-one connections is the most problematic connection in medication delivery systems for all three studied factors. As evidenced from Table 5, under the many-to-one connection type, the null hypothesis of equal proportions of

[6] Reference: The 'organizational support' factor on page 67 in this dissertation.

responses coded 0-adequate (no action needed) against the sum of remaining responses is failed to be rejected for all three factors with the following statistics: 1) Technical Complexity at 16% of adequate responses (2 out of 12 responses) with Chi-Sq = 5.33, p = 0.07 with *df* = 1; 2) Recourses Problems at 36% of adequate responses (14 out of 38 responses) with Chi-Sq = 2.64, p = 0.267 with *df* = 1; and 3) Qualification of Human Resources at 60% (6 out of 10 employees were qualified) with Chi-Sq = 0.4, p = 0.94 with *df* = 1. The other two connection types (i.e., one-to-one and one-to-many) show no statistical significance (or concerns).

Table 5. Connection Analysis Summary with Chi-Sq Statistics

Connection Analysis Summary								
Technical Complexity	One-to-One		Many-to-One		One-to-Many		Total Counts	
0 = adequate (no action needed)	44	44	2	2	10	10	102	102
1 = adequate (adjustments needed)	10	14	10	10	0	0	44	48
2 = not adequate (changes/redesign needed)	4		0		0		4	
Chi-Sq	48.1	15.52	N/A	**5.33	N/A	10.00	84.61	19.44
Resources Problems	One-to-One		Many-to-One		One-to-Many		Total Counts	
0 = adequate (no action needed)	46	46	14	14	12	12	132	132
1 = adequate (adjustments needed)	8	10	24	24	0	0	66	68
2 = not adequate (changes/redesign needed)	2		0		0		2	
Chi-Sq	61.0	23.14	38.0	*2.63	N/A	12.00	122.09	20.48
Human Resources Qualifications	One-to-One		Many-to-One		One-to-Many		Total Counts	
0 = qualified	31	31	6	6	5	5	79	79
1 = over qualified	8	9	2	4	0	1	23	27
2 = qualified (training needed)	1		1		0		2	
3 = not qualified	0		1		1		2	
Chi-Sq	26.8	12.10	N/A	*0.40	N/A	N/A	130.37	25.51
Notes: *p > 0.1 ** p > 0.01 (fail to reject the null hypothesis) N/A = (expected count < 5)								

To further analyze the technical complexity of many-to-one connections, the proportions of adequate-coded responses to resources problems in connection analysis were summarized in Table 6. The results strongly indicate that healthcare professionals suggested category 3) automated resources of medication information delivery (i.e.,

computer, software, fax machine, phone, etc.) as the most problematic resource in many-to-one connection type (16% of adequate responses). Conversely, category 1) automated resources of medication delivery (i.e., tube system) was claimed by healthcare professionals to be the least problematic (100% of adequate responses).

Table 6. Many-to-One Connection Analysis – Resources Problems

Many-to-One Connection Analysis - Resources Problems	
0 = adequate (no action needed)	%
1) Automated resources of medication delivery (i.e., tube system)	100%
2) Manual resources of medication delivery (i.e., delivery cart)	50%
3) Automated resources of medication information delivery (i.e., computer, software, fax machine, phone, etc.)	16%
4) Manual resources of medication information delivery (i.e., paper work)	75%

The empirical results from this research are straightforward, yet powerful. From the field studies at CH, the author learned that the most problematic factors are technical complexity of tasks and many-to-one connections. Therefore, when facing an operational crisis in medication delivery, the healthcare managers should first adopt a process improvement strategy proposed by TPS (Spear and Bowen, 1999) based on the following two workflow design rules:

Workflow Design Rule #1: Highly specify all medication delivery workflow procedures as to content, sequence, timing and outcome and resources used.

The literature has suggested that qualifications, experience, as well as physical and mental strengths and limitations of healthcare professionals should be taken into account while designing workflows in which humans are expected to work (Haberstroh, 1965; Reason, 1990, 1994, 2004; Leape, 2004; IOM, 2005). Therefore, hospital managers should focus on integrating intellectual strengths and limitations of humans into the design of workflow procedures. In our study at CH, one fundamental problem with technical complexity of tasks evolved. The workflow procedures with respect to content,

sequence, timing and output often did not include/concern the resources used to complete the task. In addition, healthcare professionals at CH often highlighted the poor training on resources/technologies as a main factor causing the difficulties with the process work and consequently medication errors. Specifically, fifty two out of 63 nurses (82.53%) talked about poor training for medication error reporting, and 48 nurses (76.19%) indicated difficulties with utilizing the mechanisms[7] for medication error reporting and improvement. Interestingly, 6 out of 6 pharmacy technicians (100%) pointed to the same issues as nurses[8]. So, all workflow procedures should specify not only the content, sequence, timing and outcome of task activities but also the resources used. Healthcare organizations should also focus their efforts on ensuring that their employees have the appropriate training to use the available resources/technologies. Importantly, such resources should be used to leverage the human beings capabilities to perform their job efficiently as well as safely for patients by acting as an error checking mechanism. The goal is to allow healthcare professionals to perform their work in an unambiguous, sequential and timely fashion that the resources used to complete each task are recognized as a "member" of the entire medication delivery system. In this context, the resources used for the task not only involve physical abilities of the worker but also cognitive abilities and skills used by healthcare professionals in delivering medications to individuals from prescribing to administering. Such approach can lead to simplification and standardization of workflow procedures, and consequently improved communications and coordination within teams. To some degree, the workflow design rule #1 is in agreement with TPS design rules #1 and consequently #3 proposed by Spear

[7] The percentages (%) provided in this sentence were extracted from results out of Research Objective #2.
[8] The percentage (%) provided in this sentence was extracted from results out of Research Objective #2.

and Bowen (1999). The implementation of rule #1 should help neutralize the issues with technical complexity of tasks.

Workflow Design Rule #2: Make every connection unambiguous and feedback-capable to confirm all requests and receive responses.

Organizational processes encompass multiple interpersonal connections that enable participants to communicate, share understanding, transfer information, and coordinate activities. However, the type and characteristics of effective versus ineffective connections have not been clear, yet are critical to the success of transferring the right information and ensuring better understanding and coordination of medication delivery. Based on the field studies, the author recommends to managers to first standardize all connections (starting with the many-to-one connection type) by allowing (if possible) only one type of resource (i.e., tube system) to be used for processing communication on requests and receiving responses. Second, to simplify the information exchange within a system, the managers should assure that every connection is capable of providing feedback to confirm all requests and receive responses. Such actions should eliminate unnecessary assumptions in the connections (i.e., was order received? was medication delivered?). The workflow design rule #2 is in agreement with TPS design rule #2 proposed by Spear and Bowen (1999). The implementation of rule #2 should reduce the effect of the issues with connections (especially the many-to-one connections) regarding technical complexity and resources problems.

During the two-year study at CH, the author also realized that medication delivery problems not only depend on workflow procedures but also on the culture present at the unit floor. It has been observed that the CH nurses have much job-related independence,

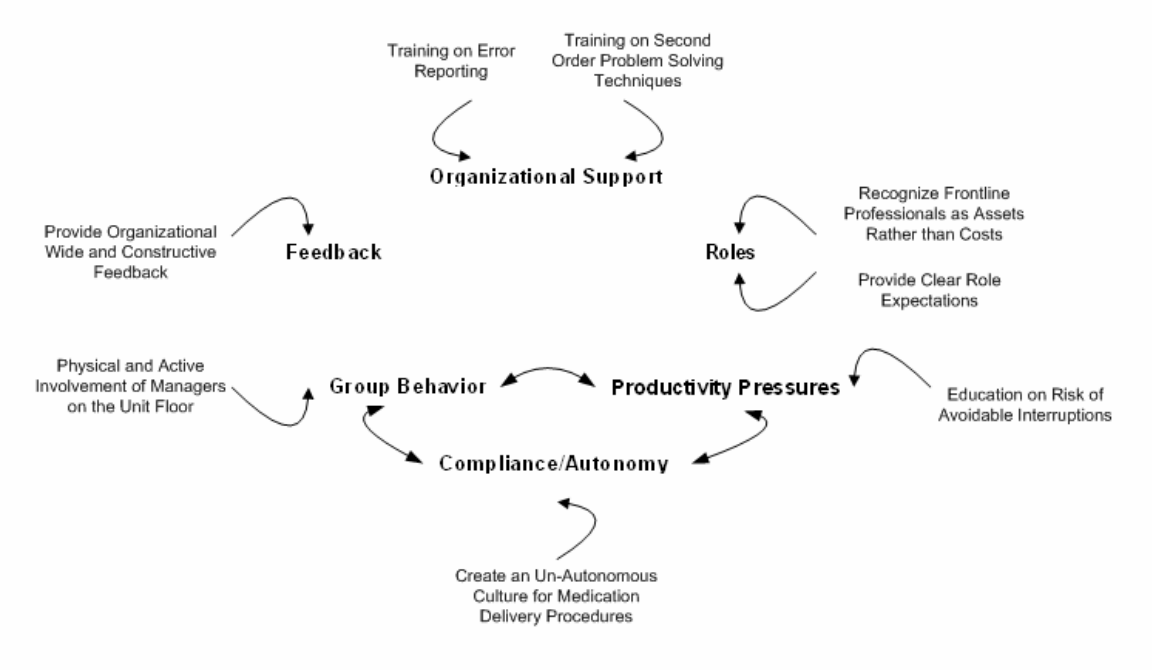
initiative, and freedom either permitted or required in their daily work activities. Some researchers reported similar observations in other healthcare settings and often referred to it as 'autonomous' culture (Slavitt et. al., 1978; Havens and Aiken, 1999; Aiken and Patrician, 2000; Tucker and Edmonson, 2002). They also showed that autonomy has been linked to higher satisfaction and productivity by promoting self-management which accordingly increases worker motivation by empowering them to make decisions that affect their productivity (Slavitt et. al., 1978; Havens and Aiken, 1999; Aiken and Patrician, 2000; Tucker and Edmonson, 2002). Similarly, the Toyota's philosophy encourages the front-line workers to have the autonomy to fix problems on their own and avoid 'work-arounds' and fix the underlying root-causes of the problem. However, contrary to such findings, the author found that the autonomous culture at hospital units with respect to following the procedures of medication delivery to be counter-productive by promoting unnecessary process variability and consequently causing medication errors and wastes. While nurses need to be creative and flexible in their work environment to deliver the best patient care it is important to differentiate between the work areas where autonomy is desired and productive vs. the work areas where autonomy is undesired and counter-productive. Medication delivery is one of the work areas where nurses need to follow strict procedures. For example, during medication administration, the nurse is to follow the "5Rs" meaning to deliver the right dose of the right medication to the right patient at the right time through the right route. This procedure involves additional procedural steps like washing hands before and after entering/leaving the room, checking two patient identifiers, informing the patient about what is being administered to her/him, etc. The evidence-based studies (IOM, 2006) have established the best procedures for all

stages in the medication delivery system. However, future empirical research is needed to further asses/improve the proposed procedures. Studies of organizations with a strong track record of high reliability and safety have shown that strict procedural compliance by frontline workers is essential for avoiding errors and for detecting threats to safety before they actually become errors and/or adverse events (Roberts, 1990; Roberts and Bea, 2001; Aiken et. al., 2002; Needelman et. al., 2002). Therefore, when facing an operational crisis in medication delivery, healthcare managers should also become active leaders in promoting procedural compliance. The goal is to eliminate the variability in the process by creating a 'un-autonomous' culture for following procedures of medication delivery. Promoting procedural compliance by the manager at the unit floor can increase her/his reputation for patient safety as well as increase the confidence of healthcare professionals in her/his leadership abilities/skills. Such managerial actions are recognized by Toyota Motor Cooperation in fourth rule-in-use as metaroutines for making changes to processes. Finally, the author also recommends managers to make the decisions of workflow design upon discussion/consensus from healthcare professionals who perform the actual process and work on the daily basis.

Results and Discussion of Research Objective #2

Figure 8 presents the theoretical model that attempts to explain the expectations needed to stimulate and sustain medication error reporting, analysis and improvement by healthcare professionals.

Figure 8. Theoretical Model of Expectations



- Organizational Support – as "in-vitro[9]" core category created upon the responses (often expressed in the form of frustrations) from nurses and technicians. Organizational support category is further grounded in the following sub-categories: 1) training ("in-vivo[10]" sub-category); and 2) complexity of reporting and improvement mechanisms ("in-vitro" sub-category). Fifty two out of 63 nurses (82.53%) talked about poor training for medication error reporting, and 48 nurses (76.19%) indicated difficulties with utilizing the mechanisms for medication error reporting and improvement. Interestingly,

[9] "in vitro" categories represent the categories created by the researchers.
[10] "in vivo" categories represent the categories elicited by the participants.

6 out of 6 pharmacy technicians (100%) pointed to the same issues as nurses. For example:

> *"…I (pharmacy technician) always try to improve or do things better, like other techs in our department. But I think I had a ten-minute training on how to use our system for reporting and improving medication errors. That is all…"*
>
> *"…Besides error reporting I (nurse) don't think there is anything else to do improvements. I don't report errors often because I have no time for it. I'm too busy doing just my job. I hardly get through the day with my duties…"*
>
> *"…our system for reporting and improvement of medication errors is not user-friendly at all! It asks for so much detail. First of all I (technician) don't have time to do it, but second of all, it is just too frustrating to fill all this information…"*

Research shows that insufficient training is in fact one of the biggest obstacles to effective organizational improvement (Huq and Martin, 2000; McFadden et al., 2006a). Healthcare organizations should provide their employees with necessary training in order to better understand the medication delivery system they are working with and the complexity of the medication errors occurring in the system. The medication delivery system involves many individuals and disciplines working together in a dynamic environment. It may be easy to see the end results (i.e., the errors occurred and reported) in a medication delivery system. However, when a medication error is caused by multiple individuals or factors across different functional departments, it is difficult to come up with an accurate explanation for the error. Without sufficient training, healthcare professionals may not value the importance of their individual contributions (whether positive or negative) to the medication delivery system or to the errors. Therefore, the research team hypothesizes (1) that a management strategy for well designed and deployed training on medication error reporting and problem-solving techniques can

increase feelings of competence and help create a culture that values improvement efforts. The feeling of competence is defined as a mediator through which the expectations influence actual problem-solving behavior and motivation as determination to pursue activities intended to lead to root cause removal over alternative responses (Huq and Martin, 2000).

- Productivity Pressures – as an "in-vitro" core category developed based on the responses from technicians and nurses. All nurses and all technicians (100%) highlighted productivity pressures as the most stress-generating factor on their daily work. In fact, recent research indicated increasing pressures on nurses with respect to efficiency requirements (Tucker and Edmondson, 2002; Tucker, 2004; Uribe et al., 2002). However, the research team observed that most interruptions during the medication delivery process at CH were caused by avoidable interactions. Other researchers have made similar observations (Hillsden and Fenton, 2006). Such avoidable interruptions often compromise patient safety (Hillsden and Fenton, 2006). Thus, the research team hypothesizes (2) that a management strategy that highlights and educates their employees about the risk of medication errors due to avoidable interruptions can increase feelings of competence and help create a culture that values improvement efforts.
- Group Behavior – as an "in-vitro" core category based on the responses from nurses and technicians. Forty four out of 63 nurses (69.8%) and 3 technicians (50%) indirectly suggested group behavior influence as another major factor behind poor medication error reporting and improvement. Unexpectedly, 31 out of 44 nurses (70.45%) at the same time indirectly self-reported the poor compliance to organizational safety standards due to group behavior influence and productivity pressures. For example:

> *"…everyday I do a lot of workarounds. Everyone does it! We need to get things done! I could do it according to the procedure, but…I don't know…this is just quicker and saves me some time..."*

Researchers also found this factor important. For example, past research (House and Dessler, 1974; Griffin, 1983; Latham and Locke, 1991) has shown that manager's behavior influences worker's motivation. Manager's presence at the floor can also help offset the motion of the popular saying that "one bad apple ruins the bunch". Thus, the research team agrees with the findings by Tucker and Edmonson (2002) and hypothesizes (3) that a management strategy that builds upon physical and active involvement of managers in medication delivery improvements can increase feelings of competence and help create a culture that values improvement efforts. This means managers are expected to spend more time and effort in the department and hospital to establish and support a culture of excellence with high commitment to patient safety.

- Roles – as an "in-vivo" category created based on the responses from nurses and technicians. Fifty five out of 63 nurses (87.3%) reported confusion about their role expectation with respect to medication delivery improvement. All technicians stated similar concerns. The conversation about the 'improvements' was often started by asking the participants if they do any improvements. For example, one of the responses was as follows:

> *"…improvements! What are the expectations? I (nurse) try to do my job as best as I can! From time to time I even suggest improvements to my manager or other nurses. But who else should I talk to about my ideas? Believe me I know a lot (laugh)…"*

Nursing personnel represent the largest group in the healthcare workforce (Bureau of Labor Statistics, 2007). In most hospitals, it is the nurses who have the most direct contact with medications and patients. According to empirical observations at CH, the

research team agrees with researchers (Mitchell and Shortell, 1997; Reason, 2004) that nurse's vigilance is necessary to prevent medication errors. Therefore, the research team hypothesizes (4) that a management strategy that recognizes frontline professionals as assets rather than costs by providing them with clear role expectations can increase feelings of competence and help create a culture that values improvement efforts.

- Feedback – as "in-vivo" core category extracted from responses by nurses and technicians. Fifty four out of 63 nurses (85.7%) specified lack of feedback as another major contributing factor that decreases the reporting, analysis and improvement rates of medication errors by nurses and technicians. Four out of 6 technicians (66.67%) pointed to the same issue. For example:

> *"…I (nurse) report medication errors. However, there is no feedback. It is like reporting to a black box! It is so frustrating, I can't even tell you! Are we (organization) doing anything to correct it? I don't know, but I would like to know…."*
>
> *"I (nurse) do not expect any rewards for reporting or improving! All I want is feedback. Feedback addressed to all of us, all the nurses at CH. Some sort of written or verbal report on what is going on!..."*
>
> *"…some feedback about error reporting would be nice. I (technician) often wonder what is going on with all these data about medication errors. All I hear about is meetings, meetings, meetings but no improvements…"*

At CH, nurses or technicians are rarely involved in meetings regarding the frequency and improvement of medication errors. In addition, the information regarding the improvement strategies developed during such meetings were rarely presented to nurses or technicians. Given that nurses or technicians have so little spare time for extensive improvement efforts, healthcare organizations should assure that the communication structures within the organization support the mechanisms for feedback to their frontline professionals. Research shows that an organizational climate that values

organization level outcomes rather than individual or group level performance can motivate cooperative behavior (Hackman, 1987). In addition, healthcare professionals may be internally discouraged to engage in medication error reporting and improvement due to an 'unenthusiastic' organizational culture. This could be explained by Mezirow's (1978) theory on perspective transformation. As Mezirow explains: "perspective transformation is the process of becoming critically aware of how and why our assumptions have come to constrain the way we perceive, understand, and feel about our world; changing these structures of habitual expectation to make possible a more inclusive, discriminating, and integrating perspective; and finally making choices or otherwise acting upon these new understandings" (Cranton, 1994). In order to change their belief, attitude, and emotional reaction, healthcare professionals must engage in critical reflection about their experiences of medication errors and error reporting and improvement, which in turn could lead to a perspective transformation. Thus, the research team hypothesizes (5) that a management strategy to provide an organization-wide and constructive group feedback to frontline healthcare professionals on medication delivery errors and improvements can increase feelings of competence and help create a culture that values improvement efforts. First, feedback can demonstrate to frontline professionals that their input is desirable and worthwhile and consequently it can motivate employees to direct more efforts toward reporting, analysis and improvement activities. Second, feedback can stimulate the worker's beliefs that organizational processes and resources needed to tackle medication delivery improvement exist and are actually used to solve problems. Third, there is evidence that feedback can enhance

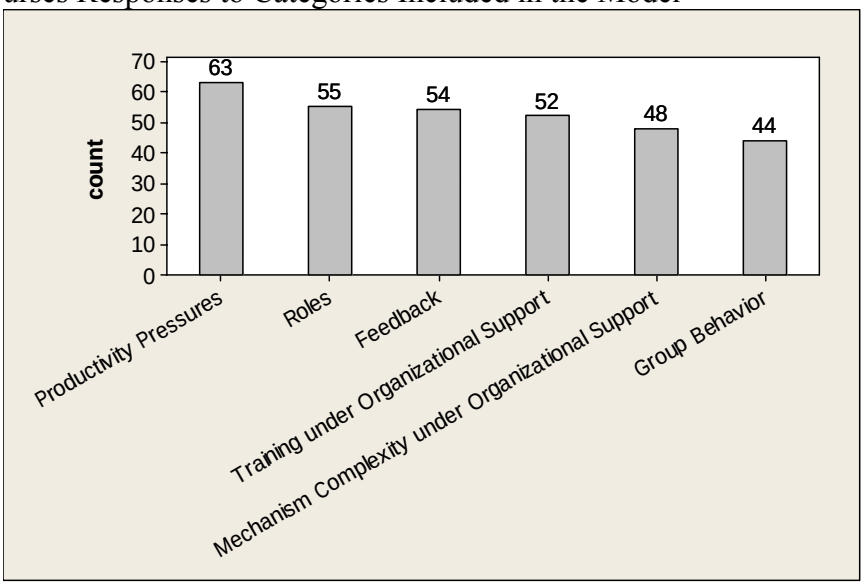
employees' psychological safety via demonstration that the medication error reporting is safe for interpersonal risk-taking (Edmondson, 1999).

- Compliance/Autonomy – as an "in-vitro" category created based on the responses from managers and top administrators. Throughout the research at CH, the research team encountered the situation in which the CH nurses or technicians did not comply with medication delivery procedures. A Joint Commission (2005) report showed that failures in procedural compliance account for approximately 74% of all medication errors. We argue that such poor procedural compliance may be related to employee's autonomy. Autonomy is defined as the amount of job-related independence, initiative, and freedom either permitted or required in daily work activities (Slavitt et al., 1978). It has been linked to higher nurse satisfaction and productivity (Havens and Aiken, 1999; Scott et al., 1999; Whitley and Putzier, 1994; Aiken and Patrician, 2000), because it promotes self-management, which accordingly increases worker motivation by empowering them to make decisions that affect their productivity (Campion et al., 1993; Hackman, 1987; Janz et al., 1997). To gain a deeper understanding on how compliance and autonomy interact with each other during medication delivery, a study at CH promoting nurses autonomy was designed and performed. The study included 38 experienced registered nurses, which were observed for approximately 80 hours. The statistics from the study indicated a considerable failure to demonstrate procedural compliance on the nurse's part. Based on the study results, the research team concluded that unstructured autonomy potentially could have negative effect on a nurses' compliance with respect to medication errors. Thus, the research team hypothesizes (6) that an 'un-autonomous' culture with respect to medication delivery compliance can increase feelings of competence and help create a

culture that values improvement efforts. First, the 'un-autonomous' culture should include simplified and standardized policies/procedures for medication delivery. Second, the 'un-autonomous' culture should include policies/procedures that include almost all variables in the process of delivering medications, so that autonomous decision-making is eliminated. Third, the policy/procedures should be clearly communicated and deployed to all healthcare professionals working with medications. Fourth, a program for continuous improvement of medication delivery policies/procedures and educational training should be developed.

To further analyze the research finding, we performed the Chi-Sq statistic for categories with nurses' responses at $\alpha = 0.05$ significance level and the total number of possible responses $n = 315$ (63 responses times 5 categories). The "goodness-of-fit" statistic is often used to reflect the magnitude of discrepancies between the observed (or categorized) and expected responses. In other words, the null hypothesis (H_o) that all categories are equal $(\pi = 0.1667)$ was tested against the alternative hypothesis (H_a) that at least one proportion differs $(\pi_i \neq 0.1667)$. Categorical data is summarized graphically in Figure 9. The Chi-Sq value of $X^2 = 13.5236$ (with p-value = 0.0189 at 5 degrees of freedom) is under two assumptions: 1) data comes from simple random sample; and 2) each expected count is greater then 5 $(n\pi \geq 5 \rightarrow 63 \times 0.1667 = 10.05 \geq 5)$. The results suggest that the null hypothesis H_o that all categorical proportions are equal can be rejected at $\alpha = 0.05$. To investigate which categories differ, an "*ad-hoc"* follow-up analysis was performed.

Figure 9. Nurses Responses to Categories Included in the Model



It was concluded that productivity pressures and group behavior are the largest and smallest proportions, respectively (this can also be seen from the bar chart in Figure 9). The results also show that 70.45% of nurses in this study that indirectly self-reported the poor compliance to organizational safety standards reported group behavior as well as productivity pressures as one of the major factors behind poor medication delivery reporting, analysis and improvement. Such insight prompted us to further consider how compliance is related to group behavior and productivity pressures? From one prospective, if we use the productivity pressures factor as most significant "voice" of nurses, we could reason that nursing staffing levels per patient day are inappropriately establish resulting in procedural workarounds and consequently medication errors. However, if we use nurse's cognition as a personal mediator through which the group behavior influences compliance from another prospective, we could reason that nurses use group behavior and productivity pressures to justify the poor compliance to medication delivery procedures and therefore remove the blame from themselves. Again,

using Mezirow's (1978) theory on perspective transformation, we could potentially explain such behavior using disorienting dilemma phenomena, which is triggered by an identity crisis or major life transition. Perhaps such identity crisis occurs in healthcare professionals, like nurses, while entering an organizational setting with pre-established norms and values on behavior and productivity which are then psychologically enforced and reinforced to establish a uniformity of the organization.

Results and Discussion of Research Objective #3

Figures 10 to 12 depict the scanned images of a completed improvement tool by a nursing student. In general, the tool is based on the M2I method which combines visual or schematic representations (current and future state maps) of a medication delivery system with the following 9-step systems analysis procedure: 1) identify problem area; 2) describe the problem; 3) draw diagram or flowchart of current state map where problem exists; 4) describe why the current system is wrong (not ideal) to cause the problem; 5) describe what needs to be done to fix the problem; 6) describe when it needs to be done; 7) describe who is responsible (key team players and/or key departments); 8) draw diagram or flowchart of future state map (targeted system) that will solve the problem; and 9) describe project success measurement plan. Both current and future state maps should be as "constructively simple" as possible.

Figure 10. “Map to Improve” (M2I): Page 1 Example.

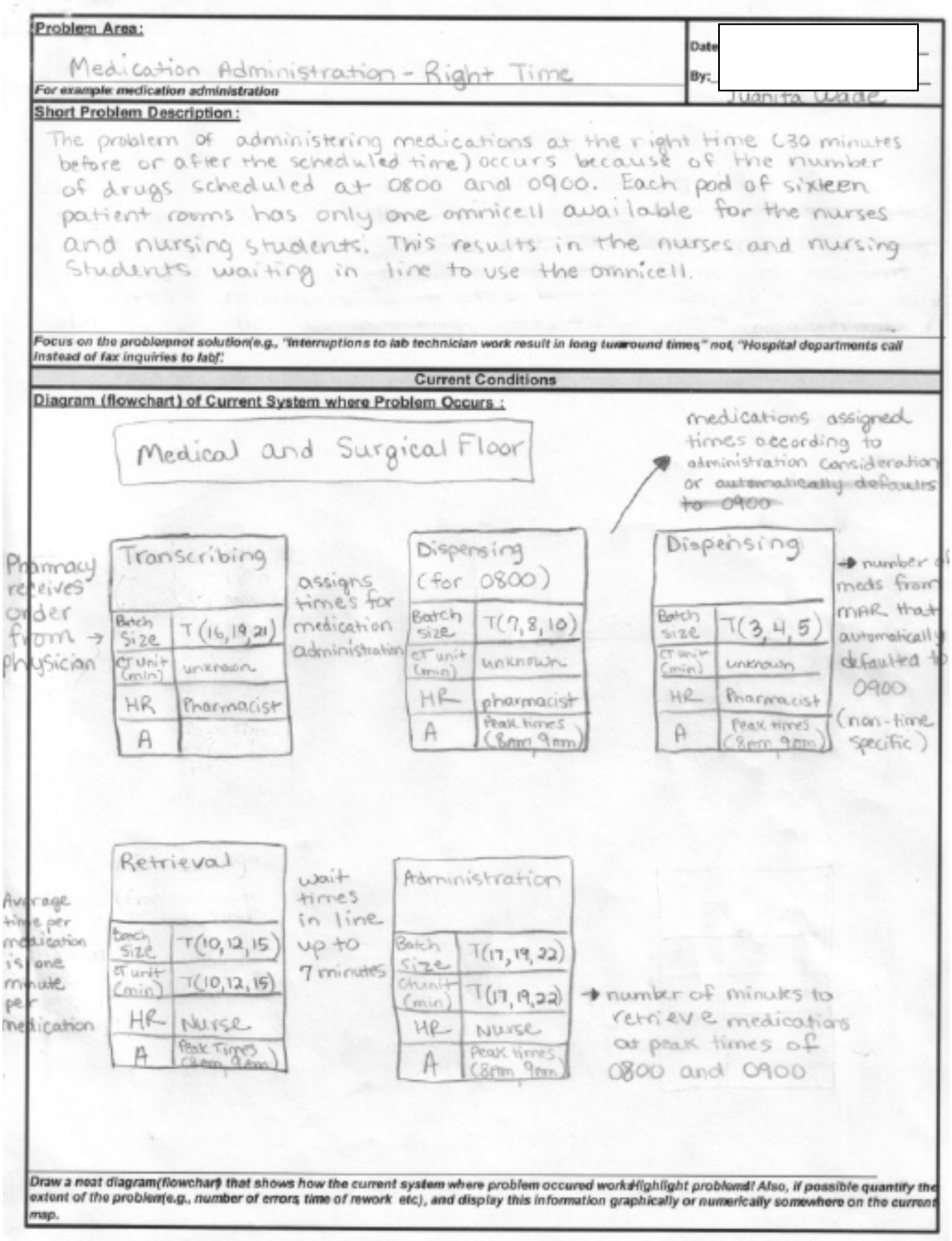
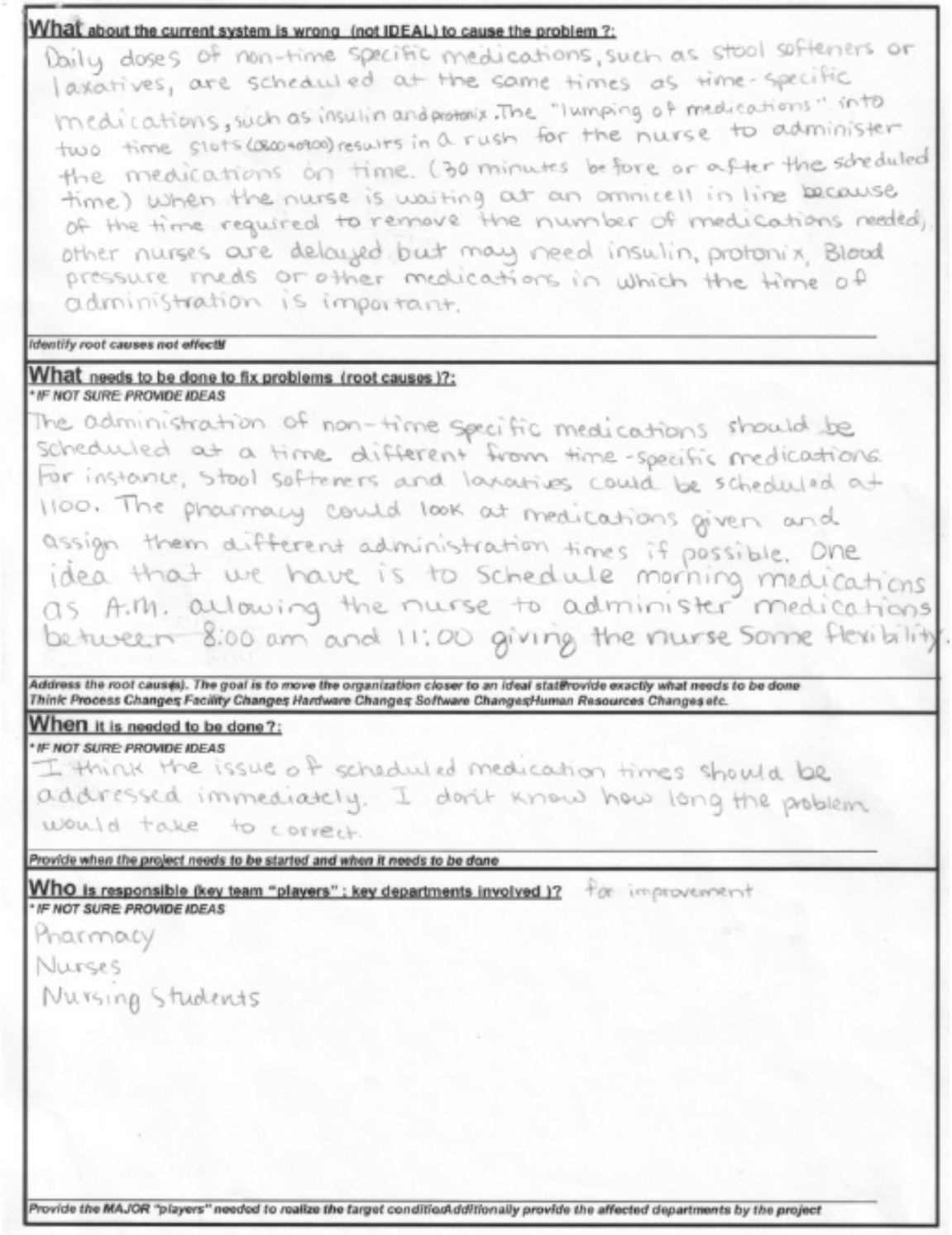


Figure 11. "Map to Improve" (M2I): Page 2 Example.



What about the current system is wrong (not IDEAL) to cause the problem ?:

Daily doses of non-time specific medications, such as stool softeners or laxatives, are scheduled at the same times as time-specific medications, such as insulin and protonix. The "lumping of medications" into two time slots (0800+0900) results in a rush for the nurse to administer the medications on time. (30 minutes before or after the scheduled time) when the nurse is waiting at an omnicell in line because of the time required to remove the number of medications needed, other nurses are delayed but may need insulin, protonix, Blood pressure meds or other medications in which the time of administration is important.

Identify root causes not effects!

What needs to be done to fix problems (root causes)?:

** IF NOT SURE: PROVIDE IDEAS*

The administration of non-time specific medications should be scheduled at a time different from time-specific medications. For instance, stool softeners and laxatives could be scheduled at 1100. The pharmacy could look at medications given and assign them different administration times if possible. One idea that we have is to schedule morning medications as A.M. allowing the nurse to administer medications between 8:00 am and 11:00 giving the nurse some flexibility.

Address the root cause(s). The goal is to move the organization closer to an ideal state!Provide exactly what needs to be done
Think: Process Changes; Facility Changes; Hardware Changes; Software Changes;Human Resources Changes etc.

When it is needed to be done?:

** IF NOT SURE: PROVIDE IDEAS*

I think the issue of scheduled medication times should be addressed immediately. I don't know how long the problem would take to correct.

Provide when the project needs to be started and when it needs to be done

Who is responsible (key team "players" ; key departments involved)? for improvement

** IF NOT SURE: PROVIDE IDEAS*

Pharmacy
Nurses
Nursing Students

Provide the MAJOR "players" needed to realize the target condition.Additionally provide the affected departments by the project

Figure 12. "Map to Improve" (M2I): Page 3 Example.

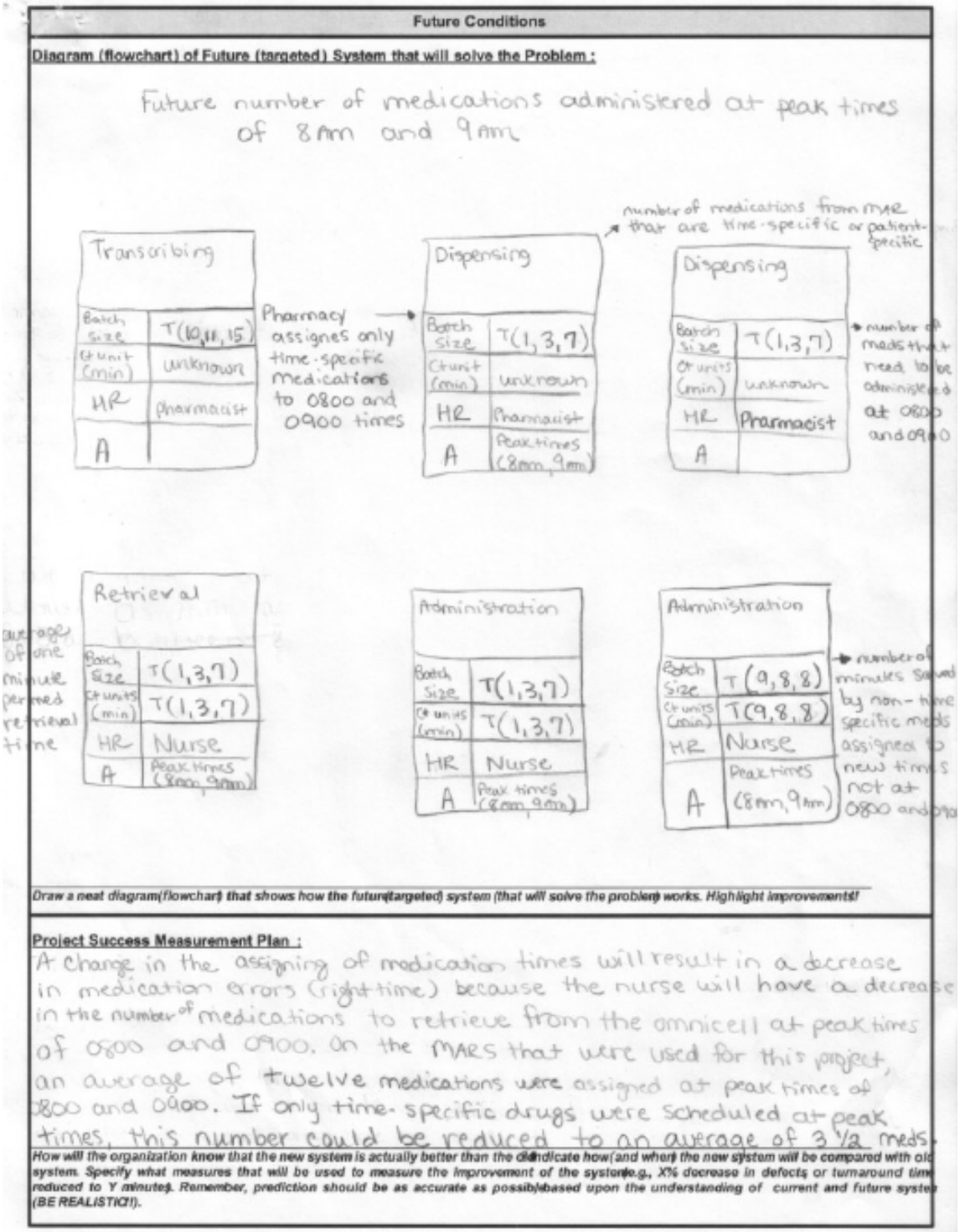


Table 7 presents the statistical summary of the predictor, control and criterion variables. One student has denied taking the survey for unknown reasons.

Table 7. Summary of the Nurses Responses to Survey Questions

Predictor	Count	Mean	StDev	Min	Q1	Median	Q3	Max	Range	A-D p-value	Cronbach's alpha
Q1 – Q2	15	3.333	0.8	1	3	3.5	4	4	3	<.005	0.85
Q3 – Q4	15	3.333	1.1	1	2.5	3.5	4	5	4	0.08	0.61
Q5 – Q6	15	3.4	0.8	2	3	3.5	4	4	2	<.005	0.9
Q7 – Q8	15	2.6	0.9	1	2	2.5	3	4	3	0.03	0.81
Q9 – Q10	15	2.7	1	1	2	3	3	4.5	4	0.02	0.93
Q11 - Q12	15	3.233	0.9	2	2.5	3	4	5	3	0.06	0.83
Q13 - Q14	15	3.433	0.7	2	3	4	4	4	2	<.005	0.84
Q15 - Q16	15	2.933	0.7	2	2.5	3	3	4	2	0.01	0.91
Control	15	3.867	1.1	2	3	4	5	5	3	0.03	N/A
Criterion	15	3.833	1.1	1.25	3.25	4	5	5	4	0.1	N/A

Using Anderson-Darling test at significance level of 0.1, the evidence suggested that all variables are normally distributed. Next the reliability measure of a psychometric instrument was calculated using Cronbach's alpha for each set of questions under every testable predictor variable in the survey. All Cronbach's alpha fell between 0.6 and 0.95, an acceptable range to ensure reliability of the survey questions (Robinson et al., 1991).

Table 8 presents bivariate correlations, means, and standard deviations for the predictor, control and criterion variables. All correlations between predictor variables are below 0.75, the level commonly considered as problematic in qualitative research (Mason and Perreault, 1991; Pelled et. al., 1999). Following Garsen's (2002) and Cohen's (1988) guidelines for the interpretation of a correlation coefficient in qualitative research using psychometric instrument, the criterion variable is strongly and positively correlated with the predictor variable Q1 – Q2 (memorizing via organized documentation) ($r = 0.78$, $p < 0.00$) and control variable (following the M2I process) ($r = 0.82$, $p < 0.00$). In addition, the criterion variable has a positive correlation with medium strength with Q13 – Q14

(systems thinking via visualization) (r = 0.46, p = 0.09) and a negative correlation with medium strength with Q5 – Q6 (brainstorming via visualization) (r = -0.45, p = 0.09). It can also be spotted that the correlation between criterion and control variable has a positive correlation with high strength. The rest of the correlations between predictor variables and the criterion variable can be considered as low strength or neutral.

Table 8. Summary of Correlations, Means and Standard Deviations for Variables

	Q1 - Q2	Q3 - Q4	Q5 - Q6	Q7 - Q8	Q9 - Q10	Q11 - Q12	Q13 - Q14	Q15 - Q16	Control	Criterion
Q3 – Q4	0.62									
	**0.01									
Q5 – Q6	-0.23	0.15								
	0.41	0.61								
Q7 – Q8	0.21	0.31	0.28							
	0.45	0.26	0.32							
Q9 – Q10	0.42	0.61	0.27	0.33						
	0.12	**0.02	0.34	0.23						
Q11 - Q12	0.31	0.69	0.11	0.33	0.7					
	0.27	***0.00	0.69	0.24	***0.00					
Q13 - Q14	0.54	0.73	-0.26	0.27	0.35	0.6				
	**0.04	**0.00	0.34	0.33	0.2	**0.02				
Q15 - Q16	0.28	0.44	0.32	0.48	0.41	0.12	0.28			
	0.32	0.1	0.24	0.07	0.13	0.68	0.31			
Control	0.82	0.44	-0.4	0.05	0.03	0.04	0.54	0.19		
	***0	0.1	0.14	0.86	0.92	0.9	**0.04	0.51		
Criterion	0.78	0.35	-0.45	0.03	-0.04	0	0.45	0.13	0.92	
	***0	0.2	*0.09	0.91	0.88	0.99	*0.09	0.65	***0	
Mean	2.83	2.83	2.9	2.1	2.2	2.73	2.93	2.43	3.87	3.82
SD	0.79	1.1	0.78	0.95	0.96	0.9	0.73	0.68	1.06	1.09

Notes: N=150 *p<.1 **p<.05 ***p<.01

As evidenced from Table 8, the similar pattern of correlations, however with slightly different r-values, can be found between the control variable and predictor variables.

Table 9 presents the results of multiple regression analysis. Model 1 is the multiple regression of predictor variables against the criterion variable. Model 2 is the multiple regression of predictor variables and control variable against criterion variable.

The results indicate that only Q1 – Q2 (memorizing via organized documentation) in model 1 is a significant predictor of process improvement (t = 3.17, p = 0.019). Model 2 does not signify the same results due to positive and high correlation between criterion and control variable.

Table 9. Summary of Coefficient Analysis for Models 1 and 2

	Model 1				Model 2			
Predictor	**Coef**	**SE Coef**	**T**	**P**	**Coef**	**SE Coef**	**T**	**P**
Constant	0.78	2.37	0.33	0.75	0.62	2.13	0.29	0.78
Q1 - Q2	1.28	0.4	3.17	*0.019	0.49	0.62	0.79	0.47
Q3 - Q4	-0.16	0.57	-0.29	0.79	-0.05	0.52	-0.09	0.93
Q5 - Q6	-0.1	0.43	-0.23	0.82	-0.12	0.39	-0.31	0.77
Q7 - Q8	-0.08	0.27	-0.29	0.78	0	0.25	-0.02	0.99
Q9 - Q10	-0.48	0.37	-1.3	0.24	-0.26	0.36	-0.72	0.51
Q11 – Q12	0.01	0.45	0.03	0.98	0.11	0.41	0.27	0.8
Q13 – Q14	0.32	0.71	0.45	0.67	-0.07	0.69	-0.1	0.92
Q15 – Q16	0.18	0.43	0.42	0.69	0.09	0.39	0.23	0.83
Control					0.67	0.43	1.55	0.18

Notes: * p-value<0.1
Model 1: S = 0.730 R-Sq = 0.815 R-Sq(Adj) = 0.561
Model 2: S = 0.657 R-Sq = 0.875 R-Sq (Adj) = 0.651

Table 10 shows that both models are significant (F-value = 3.31, p = 0.081 for model 1 and F-value = 3.9, p = 0.074 for model 2) and explain 81.5% (model 1) and 87.5% (model 2) of the variability in the criterion variable respectively. The remaining predictor variables in both models do not show significant relationship with the criterion variable (p > 0.1). The normal probability plots, the fitted values plots, and the ordered plots of residuals indicated no concerns with respect to the adequacy of the models. The purpose of this research was to understand nurses' perceptions of a systems engineering method, "Map to Improve" (M2I), for medication delivery systems improvement and learn how this method affects nursing students' individual and collaborative abilities to analyze and solve medication delivery problems.

Table 10. Analysis of Variance for Regression Models 1 and 2

Model 1					
Source	DF	SS	MS	F	P
Regression	8	14.135	1.767	3.310	0.081
Residual Error	6	3.199	0.533		
Total	14	17.333			
Model 2					
Source	DF	SS	MS	F	P
Regression	9	15.173	1.686	3.900	0.074
Residual Error	5	2.161	0.432		
Total	14	17.333			

The results from correlation and multivariate regression analysis strongly suggested that the nursing students perceived the M2I method as most helpful in remembering information such as words, numbers, pictures, and procedures about the studied problem (Q1 – Q2 with $r = 0.78$, $p < 0.00$). In addition, from correlation analysis only the nursing students found M2I method helpful in facilitating the improvement planning via visual representation (Q13 – Q14 with $r = 0.46$, $p = 0.09$). Also, the control variable (following the M2I process) was found to be strongly correlated with process improvement ($r = 0.92$, $p < 0.00$). Finally, the nursing students indicated that M2I does not facilitate the understanding about the root-cause(s) of the problem (Q5 – Q6 with $r = -0.45$, $p = 0.09$). The research team also measured the effectiveness of M2I in terms of process improvements and analyzed the data using multiple regression models.

From the analysis, the evidence suggests that nurses perceived certain skills prompted by the use of the M2I method as positive (+), some as negative (-) and some as neutral (+/-) with respect to individual and collaborative abilities to analyze and improve the medication delivery process. These skills are presented in the form of the following propositions:

- *Proposition 1 (+): Organized documentation increases the individual and collaborative abilities to better analyze medication delivery problems.*
- *Proposition 2 (+): Systems thinking about medication delivery via visualization increases the individual and collaborative abilities to develop relevant improvement planning suggestions.*
- *Proposition 3 (-): Brainstorming via visualization does not facilitate the individual and collaborative abilities to understand the root-cause(s) of the medication delivery problem.*
- *Proposition 4 (-/+): Distilling and grouping information via drawing system map(s) is neutral with respect to the individual and collaborative abilities to solve medications delivery problems.*
- *Proposition 5 (-/+): Linking the process flow with task(s) characteristics is neutral with respect to the individual and collaborative abilities to recognize and solve the true root-cause(s) of the medication delivery problems.*
- *Proposition 6 (-/+): Experimentation via drawing/redrawing system map(s) is neutral with respect to the individual and collaborative abilities to generate creative improvement ideas about medication delivery problems.*
- *Proposition 7 (-/+): Communication via visual representation is neutral with respect to the individual and collaborative abilities to solve the true root-cause(s) of the medication delivery problems.*
- *Proposition 8 (-/+): Linking the process flow with task(s) characteristics is neutral with respect to select/develop indicators to measure improvements to solve the true root-cause(s) of the medication delivery problems.*

The propositions, which are grounded in statistical analysis, suggest that at the heart of the nurses' perceptions the medication delivery problem solving is more effective if the nurses are able to document the work in an organized fashion at the beginning. To some degree this corroborates the usefulness of systems engineering tools like M2I for medication delivery systems analysis. Second, the visualization of medication delivery systems under study allows the nurses to conceptualize medication delivery processes at the system level, and thus to better develop an improvement plan for the identified problems. Third, counter intuitively, the nurses indicated that brainstorming via visualization does not facilitate the individual and cooperative abilities to understand the root-cause(s) of medication delivery problems. From our weekly conversations with nurses, electronic journals and M2I reports, we learned that such insight can be explained

by the fact that most root-causes of medication delivery problems reported by nursing students are grounded in qualitative phenomena like vigilance/compliance, psychological safety, productivity pressures, and/or cultural barriers. Most recent literature supports our reasoning (Reason, 1994, 2004; Tucker and Edmondson, 2002, 2003; Weingart and Page, 2004; Hillsden and Fenton, 2006). Such phenomena are rather hard to be represented and analyzed graphically via mapping. Therefore, the "return on efforts/investment" devoted by nursing students to drawing/redrawing the system map(s), linking/analyzing the process characteristics, and/or communication via visual representation (Propositions 4 to 8) seemed at most neutral.

Another potential explanation of negative and neutral propositions could be grounded in the research finding suggesting that visual representations (i.e., current or future state map) influence cognition of the creator's ideas and decisions (Bodker, 1998). In this paper the research team refers to cognition as information processing of an individual's psychological functions. As such, the visual representation of M2I maps tends to lead the individual or a team along certain steps of analysis requiring reasoning at different levels of abstraction. Abstraction is the process of generalization by reducing the information content of a concept or an observable phenomenon, typically in order to retain only the relevant information for a particular purpose (Lewis, 2006). To aid the information processing processes the M2I method, paralleling value stream mapping methodology but tailored to the hospital industry, breaks the system into manageable pieces for low level, standardized data collection and then places these manageable pieces into a high-level visual map. The M2I then relies on individual's abstraction skills to make improvements in light of the big picture (i.e. the system map). However, does

M2I visual representation evokes in nursing students the necessary abstraction skills to improve medication delivery systems? Representations may be good or poor (Johnson, 1998), and many different forms of representation exist, each potentially containing only certain or limited information needed to fully understand the current system or product, etc. (Peschl and Stary, 1998). This entails that different representations require reasoning at different levels of abstraction, and that use of a good representation potentially can yield a more complete picture of the system problem and potential solutions. Consequently, other visual representation could result in different responses to survey questions potentially generating a different set of propositions.

Results and Discussion of Research Objective #4

Based on the results of research objective # 3, the following skills that seem to lead to exceptional capabilities for medication delivery systems analysis and improvement were identified. The nursing students need to develop three helpful skills: organized documentation and improvement planning via visualizing.

First, nursing students can benefit from organized documentation during problem solving. Although, much of the discussions throughout the study period were done on qualitative phenomena like vigilance/compliance, psychological safety, productivity pressures, and/or cultural barriers, it was the analysis of quantitative data that allowed nurses to make strategic conclusions/decisions. This requires collecting specific information and using a standardized tool to communicate and investigate the problems and guide the improvement efforts. For example, without knowing the characteristics of process workflow (i.e., batch size, cycle time, etc.), a nurse may solve a problem for one process in a way that negatively affects the other processes.

Second, nursing students can benefit from visualization during improvement planning. To correctly plan for improvement, nurses often need to visualize the entire medication delivery system from prescribing to administering. In this research, the data collected via the M2I method were used to map the medication processes. While the organized documented can help nurses to describe the problem(s) it is the does not directly provide the ideas of how to fix the problem(s). When decisions to improve some specific tasks are made, a nurse must understand how her/his suggestion(s) would affect other interrelated tasks. Decisions being made should not result in negative impacts on the other units or departments, although they carry positive outcomes to a specific unit or department. Therefore, it was the visualization of the system map that allowd nurses to plan for their improvement action(s). However, only the proper planning for implementation can accomplished if the skill of visualizing is properly applied. Visualization includes understanding the flow of a process from start to finish by means of diagrams, maps, and/or flowcharts. Looking at the big picture and zooming in and out for different levels of details facilitate a deeper understanding of the general process.

All in all, currently, short-term problem solving behavior(s) dominate healthcare industry. For instance, one nursing student observed a CH nurse discovering an unidentified pill mixed into a box for another pill. To solve the problem, the CH nurse simply put it where it belonged. While solving the problem at firsthand, no one else was notified of the problem. It should be noted that the CH nurse was correct in solving the immediate problem but should have taken the issue one step further in order to identify the root cause and prevent the issue from reappearing. The author believes that class exercises in which nursing students were asked to solve instructional problems using a

systems engineering method (i.e., M2I) could prevent such short-term problem solving behaviors and help develop effective individual and collaborative skills that promote long-term problem solving.

SUMMARY, LIMITATIONS, CONCLUSIONS, AND FUTURE RESEARCH

Summary

This study is the first empirical research that used healthcare professionals' perceptions of medication delivery system and systems engineering methods to examine medication errors. It is inarguably relevant because medication-related errors harm approximately 1.5 million people in the United States, costing the nation at least $3.5 billion annually. Since the primary goal of this research was to assist the healthcare industry to cross the quality gap in the 21st century, the challenge was to manage the growing knowledge of healthcare systems and ensure that future healthcare professionals will have the routines and skills they need to use such knowledge (IOM, 2005). The major objectives of this research were as follows:

The goal of research objective #1 was to identify the major workflow factors that cause medication delivery errors based on healthcare professionals' perceptions of medication delivery system. To accomplish the research goal, three major factors, namely 1) technical complexity of tasks/connections, 2) resources problems, and 3) qualification of human resources, that cause medication delivery errors were studied. Based on the research findings from 246 hours of observations in 12 inpatient units at CH, a strategy for effective improvement of medication delivery systems grounded in two workflow design rules was proposed. Given the uniqueness of each healthcare professional and patient, the work reported for this research objective makes several contributions to the existing body of knowledge. Primarily, it specifies the strategy that seems to provide a simple and logical approach in establishing a procedural compliance in medication delivery. The purpose of the strategy is to create a 'un-autonomous' culture for following

workflow procedures in medication delivery. To accomplish such cultural shift, the manager should first become an active leader at the unit floor in promoting procedural compliance. Second, simplification and standardization of task workflows should be done accordingly that the task content, sequence, timing and outcome as well as resources used. Healthcare organizations should also focus their efforts on ensuring that their employees have the appropriate training to use the available resources/technologies. Third, all connections in medication delivery systems should be unambiguous and capable of providing feedback to confirm all requests and receive responses. The proposed strategy in this research is, to some degree, in agreement with the managerial improvement recommendations by Tucker and Edmonson (2002, 2003) and the process improvement recommendations extracted from Toyota Motor Cooperation by Spear and Bowen (1999). If properly implemented, the proposed strategy is capable of eliminating the unnecessary variations and assumptions in the process of medication delivery which cause medication errors/wastes. Consequently, this should allow healthcare professionals to spend more time on direct patient care activities that attracted them to the profession in the first place. Furthermore, the strategy should also have a positive impact on manager's image, quality of work life and retention that produce the win-win-win situation by simultaneously improving systems performance, care quality and patient safety.

The goal of research objective #2 was to investigate the expectations that stimulate and sustain medication error reporting, analysis and improvement by healthcare professionals. To accomplish this research goal, 246 hours were spent observing medication delivery processes at CH following with analysis using an iterative grounded theory method (Strauss and Corbin, 1998). The findings of this research resulted in six

hypotheses. First, to advance the understanding about medication delivery systems, medication errors, and medication error reporting and improvement, organizational support for comprehensive training on these subjects should be deployed and required by all healthcare professionals. Second, the productivity pressures, often mentioned by frontline workers as one of the major contributing factors causing the low error reporting rates and poor improvement efforts, should be offset by minimizing the avoidable interruptions. Third, to remove the undesired group behavior often caused by productivity pressures, managers should physically spend more time and effort to establish and support a culture of excellence with high commitment to patient safety and procedural compliance. Forth, healthcare organizations should start recognizing their frontline professionals as assets rather than costs. It is everybody's job to do improvements. Therefore, the role expectation with respect to medication error reporting, analysis and improvements should be well communicated to all frontline employees and continuously supported by managers and administrators. Fifth, organization-wide and constructive feedback to frontline healthcare professionals about medication delivery errors and improvements needs to be provided on a continuous basis. This research found that healthcare professionals who felt neglected and under-informed regarding the changes often responded with low motivation and discouragement towards medication error reporting, analysis and improvement efforts. The research team refers to this particular 'phenomenon' as the 'black-box' effect. Finally, all healthcare organizations should develop and support an organization-wide and 'un-autonomous' policy/procedures for medication delivery. Such policy/ procedures should include all variables in the process

to assure that autonomous decision-making on medication delivery by healthcare professionals is eliminated.

Using the survey instrument, the goal of research objective #3, was to understand nurses' perceptions of a systems engineering method, called "Map to Improve" (M2I) method. The analysis of the survey data resulted on eight propositions for effective use of engineering methods for improvements of medication delivery systems. In summary, the analysis suggest that nursing students perceive the systems engineering tools like M2I for medication delivery systems analysis as most useful because it allows them to document the work in an organized fashion. Second, the improvement planning via visualization allows nurses to conceptualize/visualize medication delivery processes at the system level, and thus are able to better develop an improvement plan for the identified problems. Third, counter intuitively, the nurses indicated that brainstorming via visualization does not facilitate the individual and cooperative abilities to understand the root-cause(s) of medication delivery problems. The author hopes that the proposed insights into these areas will result in improved strategies for professional development of healthcare providers. For example, with the emerging knowledge as gained from this research, nursing schools would consider to incorporate systems engineering methods/tools into their educational programs. The practical implication of this research extends to the development of better methods for healthcare delivery.

Finally, based on the results from research objective #3, two skills, namely organized documentation and improvement planning via visualizing, which seem to lead to exceptional capabilities for medication delivery systems analysis and improvement were identified. Organized documentation can allow nurses to make more scientific and

timely decisions on the studied problem. Improvement planning via visualizing can help nurses to understand the flow of a process from start to finish by means of diagrams, maps, and/or flowcharts. The direct benefit of this research extends to the development of nurses who are capable of performing long-lasting improvements.

Limitations

The research has several limitations that need to be recognized:

- First, the research was conducted in one organizational setting, with collection of data limited by variability in the studied inpatient hospital units and nursing students participating in the project. Therefore, the transferability/generalizability of the research findings is difficult to ascertain.
- Collecting data for research objectives #1 and #2 using participant-observer method presented several difficulties. The fact that the author had limited experience with certain aspects of medical care hindered his ability to understand some events witnessed. Further, observation is subjective to observers' beliefs which can influence what is recorded and therefore data may not accurately reflect dynamics of the situation (Miles and Huberman, 1994). Direct observation has also been shown to alter behavior, particularly motivating subjects to perform at higher levels than they would if unobserved (Burke et al., 2000).
- With respect to research objective #1, the limitation was also "what" was observed. The author did not explore the upstream (supplier) and downstream (customer) components of the medication delivery system. The author focused only on the studied medication delivery system in one hospital setting. Thus, the understanding of the system factors is incomplete.

- In research objective #2, the possibility of bias could not be eliminated. Despite all efforts made to reduce bias, the potential for some bias in this type of qualitative research still remains. Therefore, future work is required to quantitatively investigate the generated hypothesis in multiple organizational settings to triangulate and generalize the findings of this research.
- The study design in research objective #3 did not have a control group. Comparing the results of the intervention and the control groups (i.e., nursing students performing improvement projects without using the M2I method) would have given more credibility to the results. Also, the fact that nursing students had limited experience in hospital settings possibly also hindered their abilities to understand some events witnessed, which consequently could affect their project performance and survey responses. Also, a set of specific questions that only focus on the final project results was used to measure nursing students' performance. Another shortcoming of this research was the small sample size of nursing students in the survey study. The primary reason for this is that the research took place in one university with only 16 senior nursing students available. Finally, the survey study was administered at one point in time, meaning that the survey study was cross-sectional. Therefore, establishing definitive causal relationships among the study variables was not possible.
- In this research we used only one type of visual representation containing a set of specific information (i.e., batch size, cycle time, human resources, availability). However, research showed that representation influences cognition of the creator's ideas and decisions (Bodker, 1998). Therefore, the author's understanding of

medication delivery problem solving is incomplete. Perhaps different visual representation could evoke different abstraction skills to nursing students and lead to better/worse improvement ideas.

Conclusions

In conclusion, this research has the following major contributions:

1). This research advances our knowledge and understanding of the sources of medication delivery errors. Based on healthcare professionals' perceptions on the medication delivery system, a simple and logical strategy for establishing a procedural compliance in medication delivery is proposed. The purpose of the strategy is to create a 'un-autonomous' culture for following medication delivery procedures. Practically the outcome of this work provides healthcare leaders with a strategy to continuously improve patient safety and reduce system waste by concentrating on the most significant factors. Additionally, the reported results support, to some degree, the managerial improvement recommendations by Tucker and Edmonson (2002, 2003) and the process improvement recommendations extracted from Toyota Motor Cooperation by Spear and Bowen (1999).

2). Another contribution of this research is a theoretical model of expectations for effective management of medication error reporting, analysis and improvement. The model has potential to increase feelings of competence and help create a culture that values improvements. Practically, the author hopes that the proposed management strategies and discussions will help healthcare organizations to achieve satisfactory improvement in medication delivery. In addition, the proposed insights into this area have potential to enhance professional development of healthcare managers.

3). This research also provides an understanding of nurses' perceptions of a systems engineering method, the "Map-to-Improve Method" (M2I). As a result, eight propositions for effective use of systems engineering methods for improvement of medication delivery systems were identified. The author hopes that the insights into this area will result in improved pedagogy for professional development of healthcare providers. The practical implication of this research extends to the development of better methods and tools for healthcare delivery improvement.

4). Finally, two basic skills, which seem to lead to exceptional capabilities for medication delivery systems analysis and improvement, were identified. The author hopes that insight into this area will promote/ignite the future research in visual representations and cognitive processes needed for healthcare delivery improvements. Practically, the author believes that developing the proposed skills in nursing schools can help prevent the short-term problem solving behaviors and promote the much needed long-term problem solving behaviors.

Recommendations for Future Research

This work opens up new landscape for research in the area of healthcare engineering. Because of the highlighted limitations in this research, one important question remains: are the proposed insights in this research flexible enough to be truly appropriate for all healthcare settings? To answer this question, further investigations in multiple healthcare settings (including inpatient and outpatient settings) are needed for all four research objectives. Importantly, future research should take into consideration the upstream (supplier) and downstream (customer) components of medication delivery system. Thus, the understanding of the medication delivery system factors will be

complete. Future research could also perform studies to evaluate which combination of the 'expectations' can best achieve the goals of the organization. Ultimately, a relationship could be established between the degree of conformance to the proposed plan of action and the achieved outcomes. This would enable organizational leaders to determine a superior solution that will best serve their needs. The importance of properly preparing future healthcare workforce cannot be underestimated (American Association of Colleges of Nursing, 1998; Health Resources and Services Administration, 2000; National Patient Safety Foundation, 2004). To provide more statistical power to the results, a study with a large sample size of nursing students, preferably with different gender and ethnicity, and control group should be performed to validate the nursing students' perceptions of systems engineering methods. Future work should also use a longitudinal survey design with multiple measures (i.e., increased satisfaction, increased knowledge, etc.) to determine the effect of intervention of different systems engineering methods/tools. This will provide more robust results, increase the validity of the results, and protect the results against potential interpretive errors. Based on such results, future research should be able to better identify the individual and collaborative skills that seem to lead to exceptional capabilities for medication delivery systems analysis and improvement. Future research should also take a closer look into how the needed skills can be developed. Thus, professional development of healthcare professionals as well as methods and tools for healthcare improvement will be continuously enhanced.

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APPENDICES

APPENDIX A

TASK ANALYSIS INSTRUMENT

Task Analysis

Evaluator's Name:	Date:	Unit:

Short System Description:

Task ID

Task ID:

Technical Evaluation (T)

Task Workflow Sequance	Task Activity Workflow
Independent Dependent upon task(s)): Interdependent (with task(s)):	

Select Distribution (use possible best approximation)

Uniform (min,max) (U)
Triangular (min,mean.max) (T)

Batch Size (BS)	Cycle Time (CT) / unit	Available Time (AT)

Resources (R) Evaluation

Name	Evaluation
Resource 1:	
Resource 2	
Resource 3:	
Resource 4:	
Resource 5:	

R Evaluation

Adequate (no action needed)
Adequate (adjustments needed)
Not adequate (changes/replacement needed)

Human Resources (HR) Evaluation

Name	Evaluation
Employee 1:	
Employee 2:	
Employee 3:	

HR Evaluation

Qualified
Over Qualified
Qualified (training needed)
Not Qualified

Major Problems/ Improvement Suggestions

APPENDIX B

CONNECTION ANALYSIS INSTRUMENT

Connection Analysis

Evaluator's Name:	Date:	Unit:

Short System Description:

Connection ID

Conection ID:

Technical Evaluation (T)

Departments Involved in Connection	Connection Type
1. _____ 7._____ 2. _____ 8._____ 3. _____ 9._____ 4. _____ 10._____	One-to-One One-to-Many Many-to-One

Connection Activity Workflow

Select Distribution (use possible best approximation)

Uniform (min,max) (U)
Triangular (min,mean.max) (T)

Batch Size (BS)	Cycle Time (CT) / unit	Available Time (AT)

Resources (R) Evaluation

Name Evaluation

Resource 1:
Resource 2
Resource 3:
Resource 4:
Resource 5:

R Evaluation
Adequate (no action needed) Adequate (adjustments needed) Not adequate (changes/replacement needed)

Human Resources (HR) Evaluation

Name Evaluation

Employee 1:

Employee 2:

Employee 3:

HR Evaluation
Qualified Over Qualified Qualified (training needed) Not Qualified

Major Problems/ Improvement Suggestions