Application of Systems Engineering Science to the Healthcare Environment

Jonathan Mack PhD, MSN, ANP, RN
University of San Diego

UNIVERSITY OF SAN DIEGO

Hahn School of Nursing and Health Science

DOCTOR OF PHILOSOPHY IN NURSING

APPLICATION OF SYSTEMS ENGINEERING SCIENCE TO THE HEALTHCARE ENVIRONMENT

by

Jonathan Mack MSN, RN, ANP

A dissertation presented to the

FACULTY OF THE HAHN SCHOOL OF NURSING AND HEALTH SCIENCE

UNIVERSITY OF SAN DIEGO

In partial fulfillment of the
requirements for the degree

DOCTOR OF PHILOSOPHY IN NURSING

May 2010

Dissertation Committee

Cynthia Connelly PhD, RN, FAAN, Chairperson

Jane Georges PhD, RN

Linda Urden DNSc, CNS, NE-BC, FAAN

Abstract

Application of Systems Engineering Science to the Health Care Environment

This Doctoral dissertation consists of a research portfolio examining the application of systems engineering techniques to the healthcare environment. The portfolio consists of three final publishable articles submitted to meet the program requirements for the, Doctor of Philosophy in Nursing degree from the University of San Diego, Hahn school of Nursing and Health Sciences.

Article one is titled; *"Use of a bed projection tool to predict ICU bed needs* This article describes the dissertation research study in which a bed projection tool was piloted on an ICU unit to determine the tool's ability to predict inpatient bed requirements. Article 2 is titled; *"Reducing Disruptive Communication in the Health Care Setting: Use of the Crew Resource Model (CRM)"*. Crew resource is a human factor-engineering model that creates uniform team roles and communication structure. This article advocates the use of this model to assist in dealing with disruptive behaviors by healthcare team professionals. The article advocates the use of the CRM model for meeting the Joint Commission on Hospital Accreditation requirement for organization s in which a plan is implemented for dealing with disruptive communication in the health care environment (by health care team professionals). Article 3 is titled; *"Application of systems engineering to the hospital environment; has the time for a Nurse Engineer role arrived?* This article describes the evolution of systems engineering as a discipline and its historical application. The article stresses the need for Nurses to acquire an engineering skill set in order to participate in the redesign of clinical health systems, which will ensure efficiency and patient safety.

Dedication

This dissertation is dedicated to individuals in my personal life who encouraged and supported my desire to pursue Doctoral work. My mother, who is deceased, saw the potential for me to pursue nursing as a career. An educated woman and gifted writer, she would have appreciated the Ph.D. process and the learning that took place throughout my journey. She recognized Nursing as a vehicle for me to apply my talents and a personal desire to make a difference in the lives of others. Although she is not physically present to enjoy my success, I feel her spirit and best wishes. Lastly, my partner of many years, John Mule. Although he never quite understood why I was mentally absent for so many years while in pursuit of my goal, he was, nevertheless, supportive, patient, and proud of my accomplishment.

Acknowledgement

I would like to acknlowdge my dissertation Committee members who include Dr. Linda Urden, Dr. Jane George, and Dr. Cynthia Connelly. Without their constant vigilance and understanding, this Dissertation would not be possible. I especially want to acknowledge Dr. Cynthia Connelly who showed a special interest in my ability and dream to pursue doctoral work. Without her constant prodding, encouragement, support of last-minute ideas, and above all her friendship, this ultimately led to a Post Doctoral Fellowship as a Nurse Engineer.

I would also like to acknowledge Joan Burritt, R.N., DNSc, who as the Chief Nurse Executive for Scripps Memorial Hospital saw the importance of Doctorial training for nurses and the need for hospitals to create access for staff to pursue advanced training. She was responsible for creating a unique program that allowed many nurses to pursue doctoral work while maintaining full time employment. Without her vision and tenacity for creating this access through Scripps, others and I would not have had the opportunity to pursue Doctoral training.

TABLE OF CONTENTS

EXECTIUVE SUMMARY

Healthcare in the United States has been struggling with patient safety, system inefficiencies, and standards of care for many years. This dissertation cites multiple studies and articles dealing with this growing problem. One of the most important citations relates to a series of reports published from the Institute of Medicine (IOM). Those Reports indicated that although the Unties States has one of the most developed and technologically sophisticated health systems in the world, we experience serious system inefficiencies that place patients at risk. The IOM reports recommend several actions to correct this problem, which includes systems engineering as a discipline and training of healthcare professionals in the tools and techniques in basic engineering.

This dissertation comprises three articles, applying the science of systems engineering to different problems in the Healthcare industry, with the express intent to improve outcomes. Applying the tools of a Systems Engineer includes systems analysis, computer aided modeling, project design, system architecture, probability analysis, flow-charting, and technological solutions. This dissertation is comprised of three separate articles each addressing areas of health care which demonstrate unique problems amenable through application of engineering science, principles, and tools. Article 1 is titled; *"Use of a bed projection tool to predict ICU bed needs ."* This article describes the dissertation research study in which a bed projection tool was piloted on an ICU unit to determine the tool's ability to predict inpatient bed requirements. This article demonstrates an engineering tool called predictive analytics, to address a common problem occurring daily in hospital, and health agencies in the United States, which is forecasting patient volumes. Use of tools to

predict patient volumes and system needs is not a routine occurrence, as cited in the article. Valuable system resources as well as financial savings could be realized if systems could be developed to manage patient flow and predict hospital service needs more effectively.

Article 2 is titled; *"Reducing Disruptive Communication in the Health Care Setting: Use of the Crew Resource Model (CRM)".* Crew resource is a human factor-engineering model that creates uniform team roles and communication structure. This article advocates the use of this model to assist in dealing with disruptive behaviors by healthcare team professionals. The article cites numerous studies and document how disruptive communications behaviors from health professionals have not only resulted in medical errors but also effects system operations in the clinical setting. The article advocates the use of the CRM model for meeting the Joint Commission on Hospital Accreditation requirement for organizations in which a plan is implemented for dealing with disruptive communication in the health care environment (by health care team professionals). Disruptive behavior, regardless of the industry, is one of the most difficult aspects of healthcare communication systems to address. The article outlines CRM as a methodology that actively retrains healthcare professionals who have issues related to disruptive behavior and provides a positive methodology for role interactions within complex healthcare teams in general.

Article 3 is titled; *"Application of systems engineering to the hospital environment; has the time for a Nurse Engineer role arrived?* This article describes the evolution of systems engineering as a discipline and its historical application. The article stresses the need for Nurses to acquire an engineering skill set in order to participate in the redesign of clinical health systems, which will ensure efficiency and patient safety. This is the final article in the dissertation series and outlines a potential application of an engineering tool through the development of a Nurse Engineer role. The article cites industries, which utilizes engineer, and healthcare is a unique industry that would benefit from this role inclusion. The article advocates for training a Nurse instead of brining in non-clinical engineers for the important reason that clinical training in the tools of an engineer already has context, experience, and understanding of subtle health care systems that a non-nurse or non-healthcare training engineer would not posses. The article cites the majority of health care services in the United States, whether in hospitals, outpatient settings, or a public health setting is provided by a Nurse. Since Nurses provide the majority of care training nurses to apply engineering tools may not only prove the most effective and expeditious method of generating system improvements but may result in new design paradigms for the health care industry

ARTICLE ONE

Use of a Bed Projection tool to predict ICU Bed needs

Use of a bed projection tool to predict ICU bed needs

Adequate nurse staffing is a prerequisite for safe and effective nursing care for all patients. To facilitate accurate staffing patterns, patient flow, and bed allocation is a priority for nursing and health care administrators nationwide. The ability to efficiently place patients is a daily struggle that administrators must overcome to ensure safe, efficient care, but also to avoid the financial impact of emergency department (ED) ambulance diversions due to patient overload. Health care is a complex, high-tech industry in concert with a complex adaptive system, thus it does not tolerate delays between intended actions (Cipriano, 2009). The management of patient flow; specifically, the prediction of hospital bed needs is indeed one of these complex areas.

In response to the national crisis in bed management, patient flow is now targeted by accreditation bodies. The Joint Commission on Accreditation of Healthcare Organizations (JCR, 2004) has developed standards requiring hospital administrators to identify and mitigate impediments to efficient patient flow throughout the hospital. This, in effect, requires hospitals to develop focused and directed plans to improve patient flow. National health care organizations focused on improvement in clinical outcomes, have also called for the implementation of strategies to improve patient flow; The Institute for Health Care Improvements (IHI, 2004) argues "The answer to improving flow of patients' lies in redesigning the overall system-wide work processes that create the flow problems." They go on to advocate the need for application of systems techniques to improve throughput, however, they have not specifically advocated a mechanism, or design for projecting inpatient unit bed needs (IHI 2009). In response to this challenge, a simple predictive modeling mechanism was developed and implemented to improve bed flow between an emergency department and four intensive care units. This study is a next step to fill knowledge gap regarding development of methodologies to predict patient flow. The main goal of this study was (1) to examine the feasibility of utilizing a systems engineering mechanism called predictive modeling to forecast daily inpatient bed needs and (2) to examine the improvement in bed flow and decreased wait time for admission to ICU.

Background

Bed management issues are not a new phenomenon. Notably, it was delineated as a core issue in a consensus report crafted by the National Academy of Engineering and the Institute of Medicine (IOM, 2005). The report indicates that 98,000 people die each year as a result of system failures in health care delivery and details that hospitals are plagued with problems related to technology overlap, patient processing difficulties, medication errors related to human system design flaws, and delays in care due to care delivery failures. Ultimately, many of these problems result in patient harm or death. IOM (2007) argues a general strategy to improve health care inefficiency and patient safety is the adoption of systems engineering and human factor techniques.

Current methods to manage beds employed by most United States hospitals (regardless of the hospital size) is often based **not** upon forecasts or specific analytical predictions, but on a compilation of known, scheduled, in house procedures such as scheduled elective or non-emergent surgeries, interventional procedures, diagnostic procedures, and minor prospective historical trends known by staff or nursing unit leadership (Reuille, 2004).

In reality, nursing leadership on inpatient nursing units are subject to a "crystal ball approach" to predicting inpatient bed needs and, as a result, play host to daily or hourly unexpected admits (Reuille, 2004). Reuille suggests a different way of viewing the best guess aspect of bed projection that nurses practice is a more formal interpretation called human heuristics. Heuristics is defined as rules of thumb, educated best guesses, common sense, or intuitive judgments (Pearl, 1983). Regardless of the terminology, this lack of ability to predict bed usage often results in either poor utilization or lack of staff. As Asplin states (2006), this inability often results in increased overtime to bring in nurses when the volume is increased over predicted staffing levels, as well as increased wait times and delays in emergency department patients waiting for an inpatient bed. An added effect of poorly managed bed flow is the stress placed on nursing staff who must alter workflow patterns to accommodate bed census variability. In many cases, frequent nurse patient reassignment occurs to accommodate these unexpected volume changes and bed admissions. Such reassignment often results in breaks in continuity of nursing care and is linked to an increased number of nursing errors (Proudlove, 2007). Litvak (2005) argues by eliminating the variability in patient census, hospitals could reduce a portion of the stress on nurses that often result in medical errors

While few studies currently exist as research models for directly predicting hourly bed flow, many investigators have focused on forecasting total bed needs for hospitals. Current studies point to a high degree of variability, which will require different approaches to bed forecasting, beyond the standard mathematical models for predicting bed needs.

Nationally, hospitals face daily hurdles in meeting or predicting bed allocation needs. Oftentimes, the overcrowding experienced by many hospital emergency departments can be directly related to a lack of inpatient beds, and not a relative lack of emergency department beds (Asplin, 2006). Hospitals have historically responded to bed capacity issues, (or lack of), by adding additional beds (Belson, 2004). The actual number of beds needed by a hospital is not always the problem, "Rather, optimization of and improvement in bed flow may be the solution for realization of additional bed needs" (Asplin, 2006). Simmin and colleagues (1999) indicated that by improving the utilization of inpatient beds, such as better forecasting of bed needs, they were able to demonstrate improved patient throughput overall. Hospitals could potentially realize or uncover additional bed resources through improved patient throughput by utilizing predictive modeling for bed forecasting (Simmin, 1999).

Theoretical Framework

A systems theory model was used to frame and guide the study reported here. Systems theory is defined as a framework by which one can analyze or describe any group of objects that work in concert to produce some result (Walonick 2005). This could be a single organism, an organization or society, or any electro-mechanical or informational artifact. To contrast classic biologic systems theory with a patient care model in the hospital environment Asplin (2006) states, "Hospitals are constructs or collections of different elements or departments that together produce results not obtainable by the elements alone." He further describes elements or parts which can include people, hardware, software, facilities, policies, and documents, in other words, all things required to produce system-level results for a hospital (Asplin, 2006).

The definition of a hospital is very similar to that of a definition of a system. Viewing a hospital as a complex system with dependent but interrelated parts is a necessary premise of this study and assists in the perspective examination of all potential patient admit sources to a single admit source. Addressing the ICU wait times as a measure of improvement utilized the systems theory model, as admit sources effect flow and nursing bed utilization. Using a tool by charge nurses to predict their daily bed needs operationalizes the system theory within the bed projection tool.

Research Questions

In order to address the gap in research for predicting ICU inpatient bed needs, this study specifically sought to answer the following research questions:

- Is there significant differences for wait times between ICU units that utilize a bed projection tool and those that do not
- What is the accuracy of the bed projection tool in predicting daily shift bed needs for inpatient areas that utilize it, in comparison to inpatient units that do not?

Intervention - Bed Projection Instrument

The specific systems engineering methodology is a bed-forecasting tool, developed by the researcher called a bed projection instrument (BPI). The BPI consists of a spreadsheet placed on a server available to unit charge nurses who fill it out each shift. The spreadsheet fields (Figure 1A) requires the charge nurse to indicate all potential admits indicating patient name, gender, age, diagnosis, and admit source, which include the emergency department (ED), cardiac catherization lab (Cath. Lab), ICU holding areas, post anesthesia recovery unit (PACU), peri operative areas, and floor transfers. The charge nurse fills in each section of the BPI with appropriate patient information, admit source (origin of admission) and uses specific fields to indicate which patients from the corresponding intensive care unit (ICU) are predicted to transfer out of the ICU. The charge nurse utilizes available information and resources (rounds with physicians, information from primary nurse, etc.) to arrive at this transfer assessment. After the charge nurse inputs the patient information, the spreadsheet calculates the number of beds needed for the 12 hour time period to meet all potential admits e.g. the BPI calculates the number of admits indicated by the charge nurses and subtracts the number of patients leaving from the ICU to arrive at a total number of beds needed to accommodate in coming patients. The spreadsheet also incorporates a build-in factor of two additional patients, to account for unexpected admission from the floors or other sources. This factor is based upon the historical minimum number of patients admitted from the previous 18-month period and previous calendar year period. The BPI is password protected and maintained on ICU unit based computers. The BPI was introduced to Charge Nurses at a specific in-service which provided trained on the bed projection tool. Since this tool was part of a perforce improvement strategy at the felicity the Individuals were not consented to participate in the study

Methods

Design: A repeated measures pre/post test design was used to examine the influence of BPI in decreasing wait times for patients being admitted to ICUs from the ED. All study procedures were reviewed and approved by appropriate institutional review boards and administrators. Data was obtained from a 372 bed southern California hospital, where the program was created and in use on 3 ICU units. The hospital's electronic bed tracking system includes bed admission data times by nursing unit pre and post intervention. Participating units included three intensive care units (MICU, neuro ICU, CCU) with unit charge nurses completing the BPI each shift. Data base included wait times for patients admitted through the ED to an inpatient ICU bed and accuracy of bed prediction versus actual number of patient arrivals on each nursing unit (each shift per day).Existing bed admission data times by nursing unit (reporting period February 1, 2008 to February 28, 2008) before intervention was also obtained.

Measurement

Data was obtained from a 371 bed southern California hospital, where the program was created and in use on one of the Intensive care units from February 1, 2008 to September 28, 2008. This provided existing data providing study comparison data. The participating units included all three Intensive Care units (CCU, MICU, and 3ICU). The interventional tool called the bed projection tool (BPI) was completed each shift. The databases included wait times for patients admitted through the ED to an inpatient ICU bed. Accuracy of bed

The Key metrics for this study include the following:

- Wait times are defined as the amount of time calculated from when a patient is placed on admit status (and a bed is requested by the ED to the ICU charge nurse) to the time a patient arrives to the assigned ICU
- Shift was measured in eight-hour increments defined as day, evening, and night shift.
- Unit is defined as a specialty-nursing unit in which patients are intensively monitored and provided critical care interventions.
- Year was measured as either the comparison month (Entire month of February 2008) and the intervention year (entire month of February 2009)

Analysis

Descriptive statistics were utilized to analyze wait times for patients admitted to the ICUs to determine the central tendency and variability of the data. Data was compared for all admits to the ICU from the Emergency department for the month of February 2008 and compared to the admissions for February 2009. The key comparison variable was wait times for patients admitted from the emergency department to the ICU units which utilized the bed projection tool (CCU, MICU and 3ICU) and compared the previous years wait times from the same units. Mean and standard deviations for admit wait times were calculated for each unit for comparison. A multifactor ANOVA (Analysis of Variance) was applied to examine change in wait times for each. Due to skewness of the wait time data Standard error and Least Squares mean is reported. Average patient admit volume was compared to previous year We utilized an alpha level of 0.05 for all statistical tests to determine significance of change.

Results

Wait time comparisons

Key metric #1

Wait times for admission, by unit, were compared to previous year (08) vs. the intervention year (09). CCU demonstrated mean wait time in minutes for day shift of (M=83.50, SD=118.09) for 08 vs. (M= 216.67, SD=61.00) minutes for the intervention year (2009), evening shift (M= 177.86, SD=84.42) minutes for 08 vs. (M=91.67, SD= 85.23) minutes for 09, and night shift (M=28.00, SD= 11.60) minutes vs. (M= 406.50, SD=376.90) minutes for 09. CCU demonstrated a singular shift improvement in the evening shift with a decrease in mean wait times of 86 minutes as compared to the previous year (Feb. 2008).

An two-way analysis of variance was conducted to investigate wait time differences in shifts and years for the for the CCU. ANOVA results presented in table 1. showed a significant main effect for shifts (F(2.76=15.55, p<.001. There was no statistically significant main effect for year (F(1,76)=.71, p>.05. Interaction between factors was not significant (F(2,76)=2.39, p>.05.

SOURCE	TYPEIII SS	df	Mean Squares	F-ratio	p-value
Shift	643.358	2	321.679	15.555	0.000
Date	14.803	1	14.803	0.716	0.400
Date*Shift	99.057	2	49.529	2.395	0.098
Error	1,571.645	76	20.680		

Table #1, ANOVA for CCU

MICU demonstrated a day shift mean admission wait time of (M=310.00, SD=200.8) minutes vs. (M=150.00, SD=122.6) For 09, evening shift demonstrated (M=301.00, SD=529.6) minutes for 08 vs.(M= 315.67, SD=516.23) minutes for 08, night shift showed a mean wait time of (M= 226.67, SD= 195.31) minutes vs. (M=192.72, SD=234.61) minutes for 09. ANOVA results presented in table #2 showed no significant main effects for shift (F(2,27)=0.10, p=0.90, and for shift or date, (F(1,27)=0.10, p=0.74. Interactions between factors was also not statistically significant (F(2,27)=0.13, p=0.87.

SOURCE	TYPEIII SS	df	Mean Squares	F-ratio	p-value
Shift	16.173	2	8.086	0.105	0.901
Date	8.091	1	8.091	0.105	0.748
Date*Shift	20.843	2	10.421	0.135	0.874
Error	2,078.607	27	76.958		

Table #2 ANOVA for MICU

3ICU showed a mean admit day shift wait time of (M=268.44, SD=232.01) minutes for the 2008 year with (M= 191.25, SD= 191.25) minutes for 09, the evening shift showed (M= 213.92, SD=133.28) for the 08 year with (M=270.25, SD=378.04) for the 09 year, and night shift showed (M= 264.67, SD= 106.63) vs. (M=152.70, SD= 61.00) for the 09 intervention year. ANOVA results presented in table #3 showed no significant main effects for shift (F(2,94)=0.67, p=0.51, and for shift or date, (F(1,94)=3.07, p=0.08. Interactions between factors was also not statistically significant (F(2,94)=1.3, p=0.27.

SOURCE	TYPEIII SS	df	Mean Squares	F-ratio	p-value
Shift	56.271	2	28.136	0.673	0.513
Date	128.630	1	128.630	3.077	0.083
Date*Shift	108.675	2	54.337	1.300	0.277
Error	3,929.370	94	41.802		

Table #3 ANOVA for 3ICU

SICU, which did not utilize the BPI (control group) showed a mean wait time for day shift as (M=165.40, SD=225.17) for 08 as compared to (SD= 99.43, SD= 94.41) for 09, evening shift (M= 121.38, SD= 90.86) vs. (M= 203.69, SD= 225.17) for 09, and night shift showed (M= 202.50, SD= 155.16) minutes for 08 as compared to

(M= 147.99, SD=- 270.46) . ANOVA results presented in table #4 showed no significant main effects for shift (F(2,88)=2.44, p=0.094, and for shift or date, (F(1,28)=0.03, p=0.84. Interactions between factors was also not statistically significant (F(2,88)=0.99, p=0.37.

SOURCE	TYPEIII SS	df	Mean Squares	F-ratio	p-value
Shift	215.457	2	107.729	2.424	0.094
Date	81.616	1	1.616	0.036	0.849
Date*Shift	88.300	2	44.150	0.994	0.374
Error	3,910.335	88	44.436		

Table #4 ANOVA for SICU

Bed Projection Tool's Ability to Predict

The second research question this study sought to answer was, "What is the tool's ability to predict bed needs for nursing units that utilized the tool?" This study compared actual bed admits prediction results for each unit vs. the actual number of patients that were admitted on each unit (average number based upon shift). The average error rate for all units utilizing the BPI was 58%. The unit and shift that demonstrated the highest error rate was the CCU (night shift) with a 74.6% error rate. The unit and shift with the lowest error rate was the MICU demonstrating a 23% error rate in predicting the correct number of beds. We reviewed total wait time in the emergency department (time from arrival in ED until time to arrival in ICU bed) as a factor effecting tool predictability. We compared individual units and compared control unit (SICU) against the interventional units (CCU, MICU, and 3ICU) to determine any differences in mean wait times. Mean wait times by unit was higher for the MICU unit (mean of 229.0 minutes) with the shortest mean wait belonging to the SICU (160.8 minutes). The results indicated the instrument, overall, was able to accurately predict bed needs 41% of the time it was utilized

Discussion

The goal of this study was (1) to examine the feasibility of utilizing a systems engineering mechanism called predictive modeling to forecast daily inpatient bed needs and (2) to examine the improvement in bed flow through decreased wait time for admission to an ICU.

Statistical analysis indicated no significant improvement in admission wait times for units that utilized the bed projection tool (CCU, MICU, and 3ICU). When we compared the control unit that did not utilize the bed projection (SICU) that unit also demonstrated no significant change in wait times when compared to the previous year.

Factors that may have influenced our results include; this study was conducted for only a 28-day period only and this may have affected our ability to garner significant data. Additional testing of the tool (extend length of study from 1 month up to 6 months or 1 year) would assist in providing stronger statistical significance. In determining factors that affected the outcome of the study, we informally interviewed the ICU managers post study to determine factors that influenced wait times during the study. A common theme expressed by all ICU Managers was an increase patient acuity during the interventional month (Feb. 2009) across all ICUs as compared to the previous year (Feb 2008). This study did not factor in nor track acuities and this may have influenced the admit wait times. ICU managers also reported they lacked staff to immediately accommodate the increased acuity, often resulting in delays in accepting patients from the ED, to the interventional study units. The managers also indicated during the February 2008 month (comparison month) each unit would staff an admit nurse (admit nurses were extra nurses staffed each shift in order to expedite ICU admissions) and admit nurses were not staffed for the interventional month (Feb 2009) due to hospital budget issues. Another factor that was not tracked or controlled for was the rate at which patients would transfer out of the ICU. Delays in ICU transfers ultimately will affect beds available to accept admissions and this may have been a factor. Although the admission volume (actual number of patients admitted to each of the ICUs) was not a metric we included in this study it did not substantially increase as compared to the previous year and was not likely a factor affecting this studies outcome (see table #5).

The SICU was designated as the control unit and did not utilize the bed projection tool. The SICU also showed no statistical improvement in wait times despite not utilizing the bed projection tool. However, according to unit leadership performance improvement activities directed at the trauma service during the study period may have influenced our study outcome measures.

Tools ability to predict volume

The statistical analysis revealed the ability of the tool to predict bed needs often "over predicted" for each shift on average of 58%. This may be due in part to the spreadsheet's construction, which had a built in admit factor of two patients for each 12 hour shift. That admit factor coupled with the projections completed by the Charge nurses may have caused a portion of the over prediction. The tool's ability to predict bed needs is partially dependent upon the charge nurse's ability to indicate how many patients in the ICU would be transferred out each day. This study did not examine, nor control for that variability. Although variability between charge nurses in bed prediction was low based upon the consistent over prediction of the tool however, an area of further study may be directed at how Charge nurses arrive at the assessment of readiness to transfer out of the ICU. A long-term goal for this study is to have the tool self populate via down loads from existing hospital databases eliminating the need for a charge nurses to enter admit information and only document potential transfers from the ICUs.

Recommendations for Further Study

This was a pilot study to determine the feasibility of predicting bed needs by nursing units that utilized it. Further study with this tool is necessary in order to determine its effectiveness in decreasing wait times as this study was examined for a narrow window of time (28 days) only. As a result of this study, continued redesign of the tool is suggested to increase its ability to predict bed needs, including automating the functions carried out by the charge nurse (writing in patient admit sources), to eliminate the time required to research all possible bed admission entry points, (e.g. surgery, ED, floor admits, scheduled procedure admits). The organization where this study was conducted has an extensive bed management and patient scheduling system. An important next step would consist of working with the information systems department to create data linkages between all admit areas allowing the tool to self populate in order to eliminate the charge nurse from expending nursing time to manually update the tool. Automating all admit functions would ensure a higher predictive value of the tool but also increase the number of opportunities for the tool to update thus improving the predictive ability overall. Volumes for:

Unit	Shift	2008	2009	Grand Total
3ICU	D	9	12	21
	E	24	20	44
	N	3	10	13
3ICU Total		36	42	78
CCU	D	2	3	5
	E	7	3	10
	N	1	4	5
CCU Total		10	10	20
MICU	D	3	1	4
	E	5	6	11
	N	3	4	7
MICU Total		11	11	22
SICU	D	5	7	12
	E	16	16	32
	N	10	6	16
SICU Total		31	29	60
Grand Total		88	92	180

Table #5, admit volumes by unit, shift, and year

Limitations of the study

This study was conducted at a 300-bed tertiary non-profit community hospital in the San Diego area of California. The results may have been affected by the acuity, patient demographics, and length of stay inherent in a facility located in this area of the United States. Factors that were not controlled for included acuity, length of stay, and the charge nurse's ability to predict ICU patient transfers, which have significant impact on the total number and timing of available beds. This study's results may only be generalizable to the facility in which the study was performed.

Conclusion

Hospitals struggle to meet their daily bed needs in the United States and continued emphasis on bed utilization will only increase as hospital leadership struggles to address the issue of timely patient placement. Further research and development is necessary to construct analytic tools capable of providing nursing leadership and nursing staff the resources to manage and predict their daily bed requirements. This study is an early attempt to demonstrate the efficacy of such methodologies and to establish the bases for continued research in this area.

References

Armstrong, J. (2001). *Principles of Forecasting: Handbook for Researchers and Practitioners.* The Netherlands: Kluwer Academic Publishers.

Asplin, R. B. (2006). Developing models for patient flow and daily surge capacity research. *Academy of Emergency Medicine, 13,* 1109-1113.

Belson, D.R., Hall, P., Muraali, Initials & Dessourky, M. (2004). *Collaborative approach to improve patient flow at Los Angeles County/USC Hospital, final report.* Los Angeles CA. Epstein Department of Industrial and Systems Engineering.

Buede, D. (2000). *The Engineering design of systems: Models and methods.* Los Angeles Ca. John J. Wiley & Sons New York, N.Y.

Earnest, A., Chen, M. I., Ng, D, &. Sin, L. Y. (2005). Using autoregressive integrated moving average (ARIMA) models to predict and monitor the number of beds occupied during the SARS outbreak in a tertiary hospital in Singapore. *BMC Health Services Research, 5,* 36. doi 10.1186/1472-6963-5-36. Prepublication article from BIOMed Central June 1, 2005 .

Forester, J.W. (1961). *Industrial Dynamics.* New York: Wiley and c. y

Huang, X. M. (1995). A Planning model for requirement of emergency beds. *IMA Journal of Mathematics Applied in Medicine and Biology, 12,*345-352.

Institute for Health Care Improvement (2003). *Optimizing Patient Flow: Moving Patients Smoothly Through Acute Care Settings.* IHI Innovation Series white paper. Boston: Institute for Healthcare Improvement.International Council on Systems Engineering, (2006, October). *Task force on consensus paper on statement of systems engineering definition.* (A Consensus of the INCOSE Fellows). Web site citation, International Council on systems engineering

Joint Commission Resources (JCR), (2004). Managing Patient flow, strategies, and solutions for addressing hospital overcrowding, . Department of publications Joint commission resources Oakbrook Terrace Illinois

Jorion, P. (1997). *Value at risk: The New benchmark for controlling market risk.* New York: McGraw-Hill.

Kolker, Alexander (2008). Process Modeling of ICU Patient flow: Effect of daily load leveling of elective Surgeries on ICU Diversion. J. Med syst. DOI 10.1007/s 10916-008-9161-9

Litvak, E., Buerhues, P. I., Davidoff, F., Long M., (2005). Managing unnecessary variability in patient demand to reduce nursing stress and improve patient safety. *Journal on Quality and Patient Safety, 31,* 330-338.

Litvak, E. (2005). Optimizing patient flow by managing its variability. In S. Berman (Ed), *Front office to front line: Essential issues for health care leaders (pp.* 91 - 111). Oakbrook Terrace, IL: Joint Commission Resources.

Meleis, A. (2007). *Theoretical nursing, development, and progress.* Philadelphia, PA: Lippincott Williams &Wilkins.

National Academy of Engineering and Institute of Medicine, (2005). *Building a better delivery system, a new engineering/health care partnership.* Washington, DC: The National Academy Press.

National Research Council (2007). Human-system integration in the system Development Process, A new look. The National Academies Press, Washington D.C.

Pearl, Judea (1983). *Heuristics: Intelligent Search Strategies for Computer Problem Solving.* New York, Addison-Wesley, p. vii

Pollock, J. (1997). Using nonlinear analysis to describe and forecast the patient census of an intensive care unit. *Journal of Complexity and Chaos in Nursing,.*

Reuille, R. (2004). Bed control report, a computer-based system to track patient admissions delayed or rescheduled due to a bed shortage. *Journal of Nursing Administration, 34,* 539-542.

Simmin, P. P. (1999). Data and simulation modeling to determine the estimated number of primary care beds in Oklahoma. *Topics in Health Information management. 19,* 346-348.

ARTICLE TWO

Reducing Disruptive Communication in the Healthcare setting:

Use of the Crew Resource Model

Application of Human Factors to Mitigate Disruptive Communication in the Hospital Environment

Introduction

Effective communication of clinical information can mean the difference between a positive patient outcome and a tragic event. The health care environment is a complex and stressful setting, which can often exacerbate poor communication and inflame personalities that are prone to disruptive behavior. The Joint Commission (TJC) defines disruptive behavior as verbal outbursts or physical threats, including passive activities such as refusing to perform assigned tasks or quietly exhibiting uncooperative attitudes during routine activities (TJC 2008). Disruptive behaviors include: reluctance or refusal to answer questions, return phone calls or pages, condescending language or voice intonation and impatience with questions.(2) Overt and passive behaviors undermine team effectiveness and can compromise the safety of patients and The Joint Commission defines the problem as including all health care professionals; classically, this more often then not refers to physicians. Strategies dealing with disruptive behaviors are not well described in the healthcare literature and with organizations now required through TJC standards to address disruptive behavior, it is necessary to explore options for dealing with this issue and to develop new models for fostering teamwork to improve communication in high stress environments. Other organizations that focus on patient safety such as the Institute for Health Care Improvement (IHI) do not specifically address the healthcare team member's communication in terms of disruptive behavior. IHI does call for improvement in team functioning with improved communication as a method for delivering safe patient care (IHI 2009). IHI advocates that organizations adopt and implement human factor techniques, such as Crew Resource Management, as a method to effective, consistent, communication and as a key component of reliability and safety.

Background

How healthcare providers communicate and work together are major variables in healthcare safety (Kohn1999). Intimidating and disruptive behaviors in health care organizations are not rare. A survey on intimidation conducted by the Institute for Safe Medication Practices indicated 40% of clinicians have remained quiet or passive during patient care events rather than challenge or question an intimidator.(2, 10) Several surveys have found that most care providers have experienced or witnessed intimidating or disruptive behaviors.(1, 2, 8, 12, 13) Physician abuse of nurses is common, with 64% of nurses reporting they experienced some form of verbal abuse from a physician at least once every 2 to 3 months (Diaz & McMillin, 1991). In the same study, 23% of nurses reported at least one instance of physical threat from a physician, with the most common being having an object thrown at them. Likewise, in a 2002 survey of VHA hospitals, 96% of nurses witnessed or experienced disruptive physician behavior (Rosenstein, 2002).

Disruptive clinician behavior has a direct impact on patient safety as well. According to the ISMP survey, 49% of clinicians have felt pressured to dispense or administer a drug despite serious and unresolved safety concerns, and 40% have kept quiet rather than question a known intimidator. Other studies have shown that recipients of abusive behavior learn to cope by avoiding the abuser, even if this means failing to call when clinical situations warrant and avoiding making suggestions that might improve care (Diaz, 1991; Rosenstein & O'Daniel, 2005; Maxfield, et al., 2005). In one study, 17% reported that an adverse event occurred as a result of disruptive behavior (Rosenstein & O'Daniel, 2005). These behaviors are not limited to one gender and occur during interactions within and across disciplines.(1,2,7) It is important that organizations recognize that it is the behaviors that threaten patient safety, irrespective of who engages in them.

Factors that affect the likelihood of disruptive behavior can relate to gender bias in some work groups. Feminists and scientists have used oppressed-group behavior theory to explain much of nurses' work and its structure in hospitals, including nurse-physician relationships.(34, 46–54) Many scientists and writers have evoked the issue of gender as it relates to the work of nurses and the relationship between nurses and doctors. Mark and colleagues argue for theory development related to nurse staffing and patient outcomes, maintaining that one of the important and unexplored areas is the "why" of the nurse-physician relationship and the hypothesis that "enhanced" nurse-physician communication would "result in early recognition and intervention of potentially hazardous patient situations." (74 p. 13).

An underlying but contributing factor to disruptive behavior, which can lead to unsafe communication, is the method by which physicians are trained. Physicians' training stresses individual performance, which fosters high expectations for success with intolerance for errors. Physicians are trained to function at the apex of the health care environment in which individual accountability for behaviors is left to individual interpretation and accountability.

Adding this type of clinical training, coupled with the stress of high volume/high acuity clinical arenas upon individuals, can lead to behaviors that are not conducive to patient safety and often creates a culture in which individuals, usually physicians, cannot be questioned on decisions. These types of unequal power relationships can lead to unsafe patient situations as staff are reluctant to question orders or clinical events for fear of precipitating an angry or hostile encounter. Non-collaborative relationships and negative interactions between physicians and nurses can adversely affect patient care. The importance of collaboration and communication in not only the perioperative arena, but throughout the hospital, is necessary to ensure safe efficient patient care. In a study by Espin and Lingard, (13) they found through observation of errors during surgical procedures that multiple errors were related to poor-quality interpersonal relationships in the perioperative setting. Results from a 2003 survey conducted by the Institute for Safe Medication Practices (1999) showed that patient safety is at risk as a result of antagonistic work environments in which nurses or pharmacists who question medication orders are the recipients of intimidating behaviors from physicians or prescribers. In healthcare, the relationship between hospitals and nurses typically exhibits a rights-based approach. At will employment is subject to basic legal and contractual rights that cover working conditions and workplace behavior. Even where at will employment is in place, disciplinary codes are often progressive and provide some due process rights. Nurses who have clinical or behavioral issues receive progressive counseling and usually assistance in addressing their respective issues. In some states, Unions play a role in the negotiation of disciplinary standards and procedures. Sporadic adoption of a collaborative approach to relationships with nurses is on the rise (Ford 2009).

By contrast, doctors are often not employees and are often viewed as customers by hospitals. As such, there is less of a power imbalance than is the case with nurses and, in some instances, it can be argued that doctors have more power (Ford 2009). Hospitals are often reluctant to deal with disruptive behavior by doctors in one respect because of the idea that doctors are customers and they bring patients (business) to the hospital. In my past roles as Administrative Director, Chief Nursing Officer, and Chief Operating Officer, I have participated in multiple situations that involved disruptive physicians. Depending on the organization, most medical staff structures refer disruptive physician behavior issues to a committee, sometimes referred to as the Physician Well Being Committee. Most medical staffs have a committee that deals with impaired physicians who are often responsible for the review and mitigation of a disruptive physician. In my experience with physicians of this type, they often have above average clinical ability and experience and are regarded as having superior abilities, affording them latitude in their behaviors because of their extraordinary skills. These individuals are the most difficult to deal with as their behavior is often reinforced with inadequate methods of dealing with their behavior. If a disruptive physician has been referred to the medical staff by hospital administration or some other mechanism, I have found that often a meeting will take place with chief of staff or some other representative from the medical staff who usually receives guarantees from the disruptive physician. Because of the climate in the medical staff area, there is usually a hands off approach to assisting these physicians with changing behaviors. Since disciplinary action, or lack of formal coaching/mentoring does not exist, the offending physician is allowed to return to practice with only a personnel guarantee of behavior change. This often leads to reinforcing the behavior with the individuals who usually will display an immediate change in behavior only to find out in time they a have reverted to old behavior patterns.

Safety and quality of patient care is dependent on teamwork, communication and a collaborative work environment. To assure quality and promote a culture of safety, health care organizations must address the problem of behaviors that threaten the performance of the health care team (The Joint Commission).

Potential Solutions

A solution to dealing with disruptive behaviors and improving communication that contributes to unsafe communication is a human factor program taken from the aviation industry called Crew Resource Management. Crew Resource Management (CRM) has been widely used to improve the operation and safety of flight crews. The concept originated in 1979 in response to a NASA workshop that examined the role that human error plays in air crashes (NASA). CRM emphasizes the role of human factors in high-stress, high-risk environments. John K. Lauber, a psychologist member of the National Transportation Safety Board, defined CRM as "using all available sources—information, equipment and people—to achieve safe and efficient flight operations"(Lauber). CRM encompasses team training, as well as simulation, interactive group debriefings, and measurement for improvement of aircrew performance to reduce medical errors by teaching human-factor concepts to interdisciplinary teams of medical professionals.

An underlying premise of CRM is that human error is ubiquitous and inevitable. If error is inevitable, CRM can be seen as a set of error countermeasures with three lines of defense. The first, naturally, is the avoidance of error. The second is trapping incipient errors before they are committed. The third, and last, is mitigating the consequences of those errors which occur and are not trapped.

A secondary purpose to implementing the CRM model to the health care environment is to change the traditional medical culture which focuses on individual performance, an emphasis that in itself creates communication barriers. CRM specifically fosters a culture that values team performance and eliminates the traditional hierarchy that exists in medicine by leveling the field amongst the medical team members in order to foster cooperative care. This effectively places everyone on an equal footing with the physician in terms of communicating (challenging) potential issues that may endanger the patient.

An important component of CRM, as described in the aviation industry, is not centered on the technical knowledge or skills required to fly and operate an aircraft, but rather with the interpersonal skills needed to manage the flight within an organized aviation system. This is an important distinction for both aviation and application for the healthcare environment as it stresses interpersonal communication and team functioning. A key element of CRM includes training crews in acceptable ways to challenge the actions of other crewmembers and to assert safety concerns in a manner that is not only appropriate, but also expected. This has involved a shift away from a culture that such behavior is a personal attack or insubordinate to an understanding that such behavior is expected and even demanded from fellow crewmembers. This type of model for communication has potential to address disruptive communication by training staff to recognize and address those issues with the individual.

When we compare the aviation model for addressing crew interaction, crewmembers provide a passive monitoring role for the pilot in terms of his or hers decision making for the flight. Although, this may call for assertive intervention if the level of skill being displayed by the decision-maker pilot (physician) falls below a safe standard; e.g., if it is perceived by a crewmember that the aircraft may be inadvertently descending through clouds toward high ground. Applying CRM would also allow the ability for health care team members to address behaviors in an open and collegial fashion. It would not only help mitigate the inequality that often exists in the nurse to physician relationship (which often contributes to disruptive behaviors), but would allow a system oriented approach to dealing with disruptive individuals.

A hospital culture that embraces open communication between team members also allows for approaching problem situations. Implementing CRM could take the “bad guy” element out of the equation. It would not single out any one person, but address specific systems and develop teams that emphasize effective. collegial communication. An important aspect to achieving effective CRM implementation is in simulation-based training. Simulation training allows more effective in retraining individuals, especially those with actual or potential disruptive behavior traits. It also assumes that effective and safe communication between healthcare professionals and the way in which it occurs, is often related to how healthcare professionals are trained and encultered into their respective roles. Communicating clinical information effectively and safely is not always related to the technical ability to communicate the information, but often how it might be interpreted and managed by the receiving person. Often times, a culture related to communication relates to other factors including hierarchal structures. In the health care domain, especially within the hospital, the timing tends to occur around the hierarchy between physicians and nursing or ancillary staff.

Conclusion

Improving communication between healthcare members requires organizations to commit to long-term programs to not only retrain staff, but to also establish a culture which fosters professional communication standards and interaction. Healthcare teams such as surgical, emergency, and critical care areas require additional steps to ensure communication is effective and professional. This will require training to ensure that teams understand and integrate effective communication techniques into their work. This level of commitment requires all professional parties to have direct participation to ensure viable outcomes. Training or retraining health care professionals, depending on your point of view, cannot just take place in the hospital environment. Since professionals are enculturated into communication patterns and behavior models during their training programs. Medical, nursing, and allied professional programs need to adapt their training models to include emphasis on interdisciplinary communication and function with teams. Use of simulation labs for training students is an effective model for novice professionals to practice and develop effective team participation skills. By implementing programs, such as Crew Resource Management, will not only improve efficiency between health care providers but also ensure that care is delivered in the safest possible environment.

References

Drinka, T., & Clark, P. (2000). Healthcare teamwork; Interdisciplinary practice and teaching. Westport, C.T., Greenwood Publishing Group.

Ford, John (2009). Contextualizing disruptive Behavior in health is as a conflict Management challenge. Retrieved from Conflict management web site http://johnford.blogs.com/jfa/

Institute for Health care Improvement (IHI, (2009). White paper; Transforming Care at the Bedside. Institute for health care improvement, Cambridge Ma

Kohn LT, Corrigan Jm, Donaldson MS, editors (1999). To err is human; Building a safer health system. Washington Dc: national Academy Press;

Williamson J., Webb. R., Sellen A., Runciman, W.B., &Van der WaltJ.H. (1993) Human failure; Analysis of 2000 incidental reports. Anesthesia intensive Care 24(5). 678-683

The Joint Commission (2008). Disruptive behavior standards for accreditation

ARTICLE THREE

Application of Systems engineering to the Hospital environment:

Has the time for a Nurse Engineer Arrived?

Application of Systems Engineering to the Hospital Environment

Has the Time for a Nurse Engineer Role Arrived

A consensus report crafted by the National Academy of Engineering and the Institute of Medicine (IOM) states that "The health care industry in the United States is at a crossroads," and further characterizes the health care industry as "broken" (IOM 2005). The report indicates that 98,000 people die each year as a result of system failures in health care delivery and details that hospitals are plagued with problems related to technology overlap, patient processing difficulties, medication errors related to human system design flaws, and delays in care due to care delivery failures. The IOM (2005) strongly recommends a general strategy to improve health care inefficiency and patient safety is the adoption of systems engineering techniques including human factor designs. Doleter, a guest editor for Current Issues in Nursing (2006), cites a national report, Crossing the Quality Chasm (2001), which identified that health care in America is not only unsafe but also ineffective. Doleter advocates for nurses to become aware of these national reports and says that nurses must take part in the United States healthcare redesign to ensure quality patient care (2006).

Health care industry experts such as Jerome Grossman, MD (2008) wrote in his seminal article that health care is under-invested in mathematical/conceptual tools which could be utilized to analyze and process the complex systems that exist in health care. Grossman argues most health care providers lack the capacity to translate the rapidly expanding stream of diagnostic and therapeutic advances in medical science into high quality, affordable health care. In addition, health care leaders (i.e. retired chairmen and chief executive officer of the Kaiser Foundation Health Plan), indicate 30 to 40 cents of every health care dollar is associated with, "overuse, underused, misuse, duplication, system failures, unnecessary repetition, poor communication and inefficiency. Lawrence (2005) recommends solutions, including an engineering approach, must be applied in order to address these issues. IOM (2005)

Recommendation 5-3, from the IOM report, calls for integration of systems engineering tools and technologies into the health care training curriculum as a mechanism for integrating systems engineering (S.E.) to the hospital environment. By incorporating the two domains (health care and engineering), improvements in patient safety and quality could be realized, similar to outcomes in non health care industries. A "vigorous partnership" between engineering and health care is needed for health care to address system imbalances (IOM 2005). Yet, although a strong alliance and work partnership is necessary between the engineering community and health care leaders, engineers are described as handicapped in their communication/interaction within the health care team because the disciplines lack a common vocabulary (IOM).

As recommended by the IOM report, 5-2, a potential solution to this problem of applying systems engineering and human factors directly to the clinical areas is to equip clinicians, such as nurses, with the education and skills of industrial or operations engineers. Although national nursing organizations such as the American Organization of Nurse Executives (AONE 2009) and the American Academy of Nursing (AAN 2009) have recognized the IOM report by authoring programs and papers supporting its general recommendations; They have not advocated for specific training of nursing professionals within the engineering domain.

Nurse engineers could provide the clinical and engineering leadership for process improvement, human factor application, and systems design/implementation within the healthcare environment. Although engineering is not a fundamental skill set possessed by the majority of nurses or healthcare leadership, nurses are the individuals in many organizations who are called upon to design and execute clinical systems in the hospital setting.

Review of the Literature

Systems engineering is an interdisciplinary field of engineering which focuses on the development and organization of complex artificial systems (INCOSE, 2008). Systems engineering can also be defined as a technique of using knowledge from various branches of engineering and science to introduce technological innovations into the planning and development stages of a system (Buede, 2000). This process usually comprises the following seven tasks: 1) state the problem, 2) investigate alternatives, 3) model the system, 4) integrate, 5) launch the system, 6) assess performance, and 7) re-evaluate (2000). The systems engineering process is not always sequential, the tasks can be performed in a parallel and iterative manner (INCOSE, 2008).

Systems engineering (S.E.), as a discipline, had its inception during World War II to facilitate the movement of troops and supplies in an organized coherent fashion (Machol, 1957). The Department of Defense began adopting systems engineering in the late 1940s with the initial development of missiles and missile-defense systems (Machol, 1957). The term systems engineering dates back to Bell Telephone Laboratories in the early 1940s. Hall (1962) asserts the first attempt to teach systems engineering came in 1950 at Massachusetts Institute of Technology by Gilman, Director of Systems Engineering at Bell Labs.

Postwar growth in the field of S.E. was spurred by advances in electronic systems and by the development of computers and information theory. Buede (2002) also describes systems engineering as usually involving or incorporating new technology, such as computers, into complex, man-made systems, wherein a change in one part affects many others. Systems engineering crossed into the manufacturing sector in the early 1960s and 1980s with large manufacturing companies such as Toyota, Motorola, biopharmaceutical, and other manufacturing has made strides in cost reduction and producing efficiency by implementing S.E. techniques. S.E. has strong roots in the governmental agencies such as the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) where it is has continued to evolve since World War II. A recent shift in systems engineering occurred in the last 15 years towards a model that more closely incorporates the unique human elements into the system design and operation. This shift has taken root in the military sector as a crucial element in successful design and implementation of systems (incorporating human factors) which result in successful mission outcomes.

The International Ergonomics association defines Ergonomics (or human factors) as the scientific discipline concerned with the understanding of interactions among humans and system elements, while applying theory, principles, data, and methods to design, in order to optimize human well-being within an overall system performance model (IEA 2000). The idea in a strong interdisciplinary model integrating not only systems engineering but human factors as a composite model, was an outgrowth of a request by the military to the academy of engineering to assist in addressing mission problems with system engineering approaches (NRC 2007). The Committee on Human-System Design Support for changing technology was commissioned jointly by the Army Research Laboratory and the Air Force Research

Laboratory of the U.S. Department of Defense (NRC, 2007). This alliance, established through the National Research Council (NRC), demonstrated many systems have failed because the role of humans was considered only after design problems were identified (NRC, 2007). The committee concluded the definition of user requirements should begin when the system is first being conceived, and those requirements should continue to provide important evaluation criteria up to the time the system is placed in use (NRC, 2007). Application and integration of human factors, imbedded in the system design, is a strong recommendation by organizations such as the Institute for Health Care Improvement (IHI, 2008), that advocate this process in areas such as patient flow and decreasing medication errors in the medication administration process (IHI, 2008).

A model designed in the civilian sector that integrates both systems engineering and human factors into one cohesive model is the Systems Engineering Initiative for Patient Safety, (SEIPS, [Carayon, 2000]). Developed by researchers at the University of Wisconsin, the model integrates three steps: 1) defining and designing the content and the implementation plan of the intervention, 2) implementing the intervention, and 3) institutionalizing the intervention (Carayon 2000). This engineering process is patient focused with an emphasis on design of systems to maximize safety and quality where it is applied. Although health care specific, the literature does not represent wide spread use of this model.

Application of systems engineering techniques and concepts to health care has progressed recently with the IOM (2005) advocating the integration of engineering techniques found successful in other industries such as manufacturing, airline, and semiconductor. Organizations that are considered leaders in application of systems engineering include the Veterans Administration, Kaiser Permanente, and the Mayo Clinic (Dec. 2008). At a recent speaking engagement, Dr Dennis Cortese, CEO and President of Mayo Clinic Rochester, indicated the Mayo organization has utilized systems engineering techniques, including the electronic medical record, for decades and, areas where it was applied, have shown the greatest success (Cortese presentation 2008). He further states that utilizing an integrated approach has helped Mayo realize strides in patient medical information accessibility irrespective of geographic location of the provider. Cortese advocates organizations embracing systems engineering technologies and techniques for general improvement in processes and functions. The Mayo Clinic utilizes engineers who are health care specific, however they are not clinicians (Dec 2008). The Mayo Clinic has recently advocated the inclusion of systems engineering techniques, which includes human factors to improve safety in such areas as the surgical services department (Sundt, 2008). By adapting aviation safety techniques such as the human factors analysis and classification system, Mayo surgeons were able to identify error prone processes in the surgical service and take action to improve those processes (Sundt, 2008).

Organizations that have taken steps to adopt some minor forms of engineering tools include a particular methodology called Six Sigma. Six Sigma is a process improvement methodology developed by Motorola corporation, (based partially on the work of Deming who was an early architect of systems engineering theory), consisting of a group of engineering techniques. Those techniques focus on eliminating defects through reduction of variation in manufacturing processes (Motorola 2009). Six Sigma also relies heavily on the concept of eliminating variations in processes, statistical data analysis, and strong problem-solving techniques applied to systems.

For more than a decade, companies such as General Electric, Motorola, and Toshiba have applied Six Sigma to foster quality and process improvement. Individuals are identified by the organization and sent to specific training, resulting in different levels of expertise requisite on the length (level of responsibility) for each six-sigma course, (green belt provides project oversight, black belt six sigma are individuals who design projects/experiments and evaluate statistics for potential projects) (Motorola 2009). Six Sigma incorporates many elements of systems engineering into a focused certification program easily implemented by organizations. Although Six Sigma employs engineering tools and some methodologies, it does not prepare practitioners adequately to apply the entire systems engineering domain necessary for addressing the complexities of the health care environmental.

Current Healthcare Trend

Recently health care systems have started to implement process improvement strategies including structured methods. A large metropolitan, not-for-profit health care system, (5 hospitals) located in southern California, adopted Six Sigma as a process improvement methodology using a centralized model with black belts deployed to the facility level to assist in meeting specific facility goals. Utilizing Six Sigma has benefited the nursing service in multiple ways, including patient flow improvement projects and financial savings to the organization through supply chain savings. Although the system does not employ systems engineers, the adoption of S.E. principles to the nursing domain is advocated (personnel communication, Jennifer Jacoby, September 2008). Another Southern California based non profit health care system listed in U.S News and World Report's Best Hospitals as one of the top 100 hospitals, adopted multiple systems engineering techniques and applied them to areas such as bed resource management and quality improvement initiatives. By applying these techniques, the system has realized overall improvement in bed utilization and turnover (personnel communication, Joan Burritt, April 2008). In addition, the operative surgical service has adopted crew resource management, a human factor technique for improving safety in the surgical services department and having strong applications to other clinical areas. Administration advocates for the inclusion of systems engineering methodologies in the nursing domain and, feels the adoption of systems engineering techniques by nursing is the logical next step in addressing the numerous and complex systems that reside in the hospital environment. Burritt (personnel communication, April 2008) indicates she sees nurse engineers, nurses with additional training in systems engineering /human factors, as the individuals who will work side by side with leadership in the design and implementation of current and emerging clinical systems in the future.

A corporate based profit system that utilizes engineering techniques system wide, is Tenet Health Care of Dallas Texas. Vice President and Chief Nurse Executive, Gary Olney, MBA, RN, (Sept. 2008), indicates Tenet has implemented systems engineering principles in the quality department across the system. Tenet participated in the early work undertaken by the Health Care Advisory Group's system improvement work group called H-works. This was a national effort consisting of 30 pilot hospitals focusing on improving the emergency department process. Tenet has been on the cutting edge of systems improvement by utilizing operations management for years. According to Olney, Tenet has realized improved clinical outcomes by utilizing these techniques for bed resource management, patient flow, and other system wide initiatives with great success.

Although health care systems that have implemented process improvement strategies included structured methods such as Six Sigma, they still admit a lack of specially trained individuals with formal engineering training who are responsible for the design and implementation of patient care systems. All the CNE's interviewed for this paper indicated a relative lack of training amongst leadership within the engineering domain and, would welcome the ability to draw upon nursing professionals with formal preparation in engineering and human factors.

Developing an Engineering Nurse Specialty

Applications of engineering techniques are not unfamiliar to nurses. Florence Nightingale is recognized as developing (engineering) and instituting basic systems that not only improved the delivery of care, but also decreased the mortality of patients in 19^{th} century hospitals. She also utilized an important tool of the engineer, statistical analysis. Nightingale was recognized for providing statistical analysis of patient mortality in field military hospitals and was the first female to be elected to the Royal Statistical Society (Gill 2005).

A Nurse Trained in Systems Engineering is a Natural Role Evolution

Nursing staff comprises the largest percentage of hospital leadership structures and is frequently the individual who implements and manages clinical care systems (patient care related services) in U.S. hospitals. A clinical nurse who has received training at the graduate level in engineering would possess both the clinical background and the systems engineering skills necessary to provide leadership for organizations who desire the ability to address system complexity and implement system redesign. Nurse engineers would prove invaluable for the medical device industry as possessing both the clinical consultant skill set as well as the engineering background, enabling them to participate in the design, adaptation, and implementation of devices for the clinical setting.

Engineering programs have multiple degree titles and focus. Engineering programs that focus on service center occupations tend to be system or industrial engineering programs. A growing number of engineering programs have separate tracks for engineering students who wish to develop a health care focus. A nurse, pursuing an engineering specialty, could complete course work parallel to a Ph.D. program either in nursing, as a research focus, or as a separate and defined cognate focus (trained engineering practitioner). Courses necessary to acquire a practitioner level skill set would necessitate a minimum of 4 semesters of focused study within an engineering department. Engineering course work ranges from systems theory, system design, stochastic modeling, probability, human factors, and simulation modeling as a framework for developing a graduate level of expertise in systems engineering

Specialty nursing PhDs (collaboration with Schools of Engineering), could be developed that allow engineering course work to be completed simultaneously while the doctorial candidate develops a program of research around applied health engineering. Although consideration was given for the new Doctorate of Nursing Practice (DNP) as a platform for the nurse engineer, this degree option would not provide the research methodology and statistical analysis skills necessary for a nurse to function within an engineering domain. Those research skills are crucial for the engineer and are necessary for the nurse engineer to possess. Additionally, a Ph.D. prepared nurse engineer would possess the credentials that are recognized across all disciplines, allowing the nurse engineer to sit comfortably at the table with other professionals who are called upon to provide leadership and research driven innovation necessary to address the system complexities organizations face.

Summary

The health care environment in hospitals is complex and error prone. The rapid acceleration of advances in technology and health care will only continue to add to already taxed systems. The need is evident for nurses who can provide not only the clinical care, but also possess the engineering skill set to address the current quality and safety issues, as well as participate as architects of future systems and technologies we have yet to envision. Nurse engineers could potentially transform bedside care and strongly participate in the national endeavor to improve health care. The time for the nurse engineer role has arrived.

REFERENCES

AAN (2009). American Academy of Nursing. Nurses Helping Americans Cross the Quality Chasm. Retrieved Feb 2009 from http://www.nursingworld.org/search.aspx?SearchMode=1&SearchP

AACN (2004). American Association of Colleges of Nursing. Position Statement on the Practice Doctorate in Nursing , Washington, DC 20036 October 2004

AONE (2009). The American Organization of Nurse Executives. AONE and the Robert Wood Johnson Foundation: Partnering to Disseminate, Transforming Care at the Bedside (TCAB). Retrieved Feb. 2009 from http://www.aone.org/aone_app/aonetcab/index.jsp

Buede, D., (2000). The Engineering Design of Systems: Models and Methods, John J. Wiley &Sons.

Carayon, P., Schoofs Hundt, A., Karsh, B-T., (2006) Work System Design for Patient Safety: The SEIPS Model. Qual. Saf. Health Care 2006; 15; 50-i58

Dolter, K. (2006). Role of Nursing in Achieving Quality Health Care Systems. Guest editor, Current Issues in Nursing 6th edition pgs 260-280. Mosby, Inc. St Louis, Missouri.

International Council on Systems Engineering, (INCOSE)(2007). *Task force for consensus paper on statement of systems engineering definition.* A Consensus of the INCOSE Fellows. Oct. 2006.

Gill, G., (2005). Nightingales: The Extraordinary Upbringing and Curious Life of Miss Florence Nightingale. Random House Publishing, Random House Inc., New York

Grossman, J., (2008). Disruptive Innovation in Health Care: Challenges for Engineering, Volume 38 Number 1 Spring 2008. National Academy of Engineering Web Site Publications.

Hall, A. (1957)). A Methodology for Systems Engineering 1962

International Ergonomics Association(2009). The Discipline of Ergonomics. Retrieved Site March 1, 2009 From International Ergonomics Association web site http://www.iea.cc/browse.php?contID=what_is_ergonomics

Lawrence, D. (2005). Bridging the Quality Chasm. pp99-102 in Building a Better Delivery System: a New Engineering Health care Partnership, Part II. Washington, D.C.; National Academy Press.

Machol E.R. (1965). Systems Engineering Handbook. New York: McGraw-Hill,

Motorola University (2009). Quality and Six Sigma in a Global, High-Tech Environment. Retrieved March 1, 2009 From Motorola University web site http://www.motorola.com/content.jsp?globalObjectId=3070-5788

Institute Of Medicine, (IOM) (2005). *Building a Better Delivery System, A New Engineering/Health Care Partnership.* Washington, DC: The National Academy Press.

Institute Of Medicine, (IOM) (2001). *Crossing the Quality Chasm.* Washington, DC: The National Academy Press.

National Research Council(NRC) (1998). Modeling Human and Organizational Behavior: Application to Military Simulations. R.W. Pew and A.S. Mavor (Eds.). Panel on Modeling Human Behavior and Command Decision Making: Representations for Military Simulations, Commission on Behavioral and Social Sciences and Education. Washington, DC National Academy Press.