

## ***Grant Final Report***

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# **CPOE Implementation in ICUs**

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# Abstract

**Purpose:** The purpose of this project was to systematically assess CPOE/EHR in ICUs.

**Scope:** The project focused on the implementation and use of CPOE/EHR in four ICUs of Geisinger Medical Center.

**Methods:** Multiple data collection methods were used to examine the impact of CPOE/EHR on (1) medication safety and quality of care, (2) the job tasks and perceptions of ICU staff, and (3) financial value. We also studied the value of using human factors methods (i.e. usability training and proactive risk assessment) before technology implementation.

**Results:** This very large complex technology implementation had no overall negative effect. We observed some short-term negative effects, such as decreased perception of communication timeliness. These negative effects disappeared about one year post-implementation. We observed changes in job tasks done by nurses, physicians and PAs, such as increased time spent on documentation and review tasks. Our results actually show some benefit of CPOE/EHR on timeliness of IV medication delivery. The CPOE/EHR implementation was accompanied by major attention to organizational issues and change management by the organization. We demonstrated the feasibility and benefits of using human factors methods, such as usability and proactive risk assessment, before the technology is fully designed and implemented.

**Key Words:** Electronic Health Record (EHR), Computerized Provider Order Entry (CPOE), quality of care, patient safety, medication errors, adverse drug events, prospective human factors analysis, usability, perceptions of work, quality of working life

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# Final Report

## Purpose

This project had four specific aims. The goal of Specific Aim 1 was to determine the effect of computerized provider order entry (CPOE) and electronic health records (EHR) on safety and quality of care in ICUs. We examined whether the prevalence, type or seriousness of medication errors and adverse drug events (ADEs) changed after the implementation of CPOE/EHR. This part of the research also examined the processes of interception and recovery from medication errors. We examined if CPOE/EHR implementation affected care in the ICUs, as measured by infection rates, protocol compliance, length of stay, mortality rates and other indicators. We also aimed to discover if CPOE/EHR implementation reduced the time between ordering an IV antibiotic and administering the medication (antibiotic turnaround time).

Specific Aim 2 was to determine the impact of CPOE/EHR on physicians, nurses, physician assistants and nurse practitioners in ICUs. More specifically, the Job Task Analysis examined the effect of CPOE/EHR implementation on how ICU providers (i.e. attendings, fellows, residents, PAs and NPs) and nurses spend their time performing job tasks, and the frequency and duration of tasks. The questionnaire survey examined CPOE/EHR implementation and usability, and assessed the effects of CPOE/EHR on communication, coordination, quality of working life, and perceptions of patient safety and quality of care. The survey was administered to physicians, PAs, NPs and nurses in all four ICUs.

The goal of Specific Aim 3 was to determine the financial value of CPOE/EHR implementation by examining the cost of patient care in the ICUs before and after the CPOE/EHR implementation. In Specific Aim 4 we examined the role of human factors analysis in CPOE/EHR implementation. The usability analysis aimed to evaluate the usability of and satisfaction with the CPOE/EHR technology through user testing and also expand upon a previously developed participatory ergonomics model regarding the transfer of expertise from researchers to end users in the health care organization. Prior to the CPOE/EHR implementation we also developed and implemented a proactive risk assessment (PRA) methodology to evaluate potential failure modes arising from the process of immediate post-operative transfers of patients back to the ICU.

## Scope

### Background

Medication errors are common (Institute of Medicine, 2006), occurring in nearly 20% of inpatient medication doses (Barker, Flynn, Pepper, Bates, & Mikeal, 2002) and accounting for 7,000 deaths annually (Kohn, Corrigan, & Donaldson, 1999). Nearly half of medication errors are preventable (Leape, et al., 1995). A series of studies by Leape, Bates and colleagues showed that various system factors contribute to medication safety such as inadequate availability of

patient information (Leape, et al., 1995), and that medication errors and adverse drug events are more frequent in intensive care units primarily because of the volume of medications prescribed and administered (Cullen, et al., 1997). According to Bates (2000), CPOE “has probably the largest impact of any automated intervention in reducing medication errors.” CPOE technology can improve patient safety by structuring medication orders, therefore providing support for drug selection, dosing calculations and scheduling, avoiding handwriting and thus eliminating illegibility errors, providing information to the prescriber while writing an order, and checking orders for problems (e.g., drug allergy) (Bates, 2000; Kohn, et al., 1999; Schiff & Rucker, 1998). However, implementation of new technologies in health care can be problematic (Aarts, Doorewaard, & Berg, 2004; Battles & Keyes, 2002; Koppel, et al., 2005). Technologies can change the way work is being performed (Smith & Carayon, 1995) and, because healthcare work and processes are complex, negative consequences of new technologies are possible. CPOE may reduce medication errors, but may also introduce new types of errors (Koppel, et al., 2005; Sittig & Singh, 2009). Although CPOE technology can reduce medication errors by providing information on drug interaction and drug allergy alerts, such information may become a nuisance if perceived as inappropriate and outdated, especially by physicians whose workload is already high (Weingart, et al., 2003). CPOE can actually increase the time that physicians spend writing orders by as much as 33 minutes over a 10-hour period (Tierney, Miller, Overhage, & McDonald, 1993). This study examines the impact of CPOE implementation in ICUs in various domains, including quality and safety of care, financial impact and impact on ICU staff.

This study focused on ICUs for several reasons: (1) ICUs are a very significant element of the healthcare system with regard to costs, hospital beds, and extent of care; (2) medical errors, including medication errors, are frequent in ICUs; (3) ICUs are work environments where many activities occur simultaneously at a rapid pace, therefore any technology implementation needs to take into account those contextual characteristics, in particular the issue of workload; and (4) little research has examined the impact of CPOE implementation in ICUs. Several studies have shown that CPOE can significantly reduce serious and minor medication errors in both general care and ICUs (Bates, et al., 1998; Bates, et al., 1999; Chaudhry, et al., 2006; Igboechi, Ng, Yang, & Buckner, 2003; Potts, Barr, Gregory, Wright, & Patel, 2004), reduce potential ADEs (Potts, et al., 2004), and improve medication turn-around time (Mekhjian, et al., 2002), physician prescribing practices (Teich, et al., 2000) and adherence to practice guidelines (Overhage, Tierney, Zhou, & McDonald, 1997). The impact of CPOE on medication errors was found to be greater in ICUs than in other units: the rate of non-missed-dose errors (calculated per 1,000 patient-days) dropped by 86% in the ICU and by 80% in other units (Bates, et al., 1999).

The manner in which a new technology is implemented is as critical to its success as its technological capabilities (Eason, 1988; Smith & Carayon, 1995). Human factors research shows the value of performing prospective analysis before technology implementation (Chan, 2002; Wetterneck, et al., 2006). As part of this study, we performed a hybrid health care failure modes and effects analysis (HFMEA) on the OR-to-ICU patient transfer process in order to prospectively identify the potential failure modes associated with the implementation of CPOE/EHR technology. Technology usability is also related to the success or failure of CPOE/EHR implementation (Ash, et al., 2002; van der Meijden, Tange, Troost, & Hasmina, 2003). Technology characteristics can have a large influence on the usability of the technology, specifically how end users can use the various functionalities of a technology (Nielsen, 1993). In the ICU environment, because of the high workload and the high volume of medication orders

and other orders, it is very important that CPOE/EHR does not add to the workload, for instance by increasing the duration of tasks such as prescribing orders.

## Context

This research was performed at Geisinger Medical Center (GMC) in Danville, Pennsylvania. GMC is a 403-bed teaching hospital with a Level 1 Trauma Center and serves as the main tertiary and quaternary care center for Central Pennsylvania.

## Settings

This project focused on the effect of CPOE/EHR implementation in the four intensive care units of GMC. The Adult Intensive Care Unit (AICU) is a medical/surgical shock and trauma unit, while the Cardiac Intensive Care Unit (CICU) is a medical/surgical unit. The two pediatric units are the Neonatal Intensive Care Unit (NICU) and the Pediatric Intensive Care Unit (PICU). Details about these units can be found in Table 1.

**Table 1. Characteristics of GMC ICUs**

	<b>AICU</b>	<b>CICU</b>	<b>NICU</b>	<b>PICU</b>
Open/closed	Semi-closed: Critical Care is primary service; Surgical and Trauma services can write orders.	Open: any service with a patient in the unit may write orders.	Closed	Semi-closed: Critical Care is primary service, but Trauma and CVTS also write orders.
Number of beds	24	18	38 (20 ICU and 18 Special Care beds)	11
Providers (physicians and mid-level providers) (average in Spring 2007)	5 full time, 4 part time critical care intensivists, 3 upper level residents, 3 interns, 5 physician assistants	3 cardiothoracic surgeons with 10 physician assistants; 4 vascular surgeons with at least 1 fellow; 12 cardiologists with 2 fellows	5 neonatologists, 5 residents, 4 neonatal nurse practitioners	4 pediatric intensivists, 1 cardiothoracic surgeon with 1 CVTS physician assistant and 1 CVTS nurse practitioner, 4 residents
RN staff size	78 total staff	65 total staff	66 total staff	26 total staff
RN/patient ratio	1:1-2	1:1-2	1:2-3	1-2:1 (2:1 for open heart patients)
Pharmacists	One on unit, 6 am to 4 pm	One on unit, 6 am to 4 pm	Children's Hospital pharmacy is located by PICU. Two pharmacists cover NICU, PICU and labor and delivery during the day.	Children's Hospital pharmacy is located by PICU. Two pharmacists cover NICU, PICU and labor and delivery during the day.

**Table 1. Characteristics of GMC ICUs (continued)**

	<b>AICU</b>	<b>CICU</b>	<b>NICU</b>	<b>PICU</b>
Patient mix	Medical and trauma patients; surgical patients are usually post-op; no major burn patients.	All CV surgery patients and acute MI/post-catheterization; kidney, pancreas or liver transplants; overflow AICU patients.	Patients are admitted when less than 2 weeks old or within 7 days of NICU discharge.	All medical and surgical pediatric patients including kidney transplants, cardiomyopathy, congenital heart abnormalities, trauma, respiratory distress and urgent hemodialysis.
Average length of ICU stay (as of October 2007)	7.1 days	3.6 days	12.8 days	3.9 days

## Participants

The participants in this research differed for each specific aim. For Specific Aims 1 and 3 (Safety, Quality of Care and Financial), the data were gathered from hospital records, patient charts and EHR by trained research staff. For Specific Aim 2 (Impact on End Users), researchers observed the job tasks of ICU physicians and nurses, and survey data were collected from ICU attendings, fellows, residents, physician assistants, nurse practitioners and nurses. For Specific Aim 4 (Prospective Human Factors Analysis), the participants in the Proactive Risk Analysis (PRA) were Geisinger employees from the areas of the organization affected by the CPOE/EHR implementation and other stakeholders (e.g., IT staff). The participants in the Usability Evaluation were Geisinger IT staff who served as “usability coordinators”.

A comparison of the expected and final inclusion of AHRQ priority populations is complicated because we changed research sites in year two of the grant. The original research site, UW Hospital & Clinics in Madison, Wisconsin, delayed its implementation of the CPOE technology for several years. We therefore sought another research partner and selected GMC. The anticipated participation by end users in the ICUs of UW Hospital & Clinics was described in the proposal (see Table 2).

**Table 2. Expected AHRQ priority populations in the ICUs of UW Hospital**

	<b># of Subjects</b>	<b>% Female</b>	<b>% Non-Hispanic white</b>
Physicians	50	10%	Unknown
Nurses	169	90%	Unknown
Residents	182	unknown	Unknown
Respiratory Therapists	80	64%	100%
Pharmacists	27	56%	93%

The final results for the inclusion of priority populations at GMC are shown in Table 3.

**Table 3. Final AHRQ priority populations in the ICUs of GMC**

	<b># of Subjects</b>	<b>% Female</b>	<b>% Non-Hispanic white</b>
Medication Safety: Patients	1255	43.9%	94.3%
Job Task Analysis: Nurses	89	Unknown	Unknown
Job Task Analysis: Physicians, PAs and NPs	51	Unknown	Unknown
Survey: Nurses	464	88.2%	95.1%
Survey: Physicians, PAs and NPs	185	33.8%	81.5%
Usability: Participants	33	Unknown	Unknown
Proactive Risk Analysis: Participants	19	Unknown	Unknown

## **Methods**

### **Intervention**

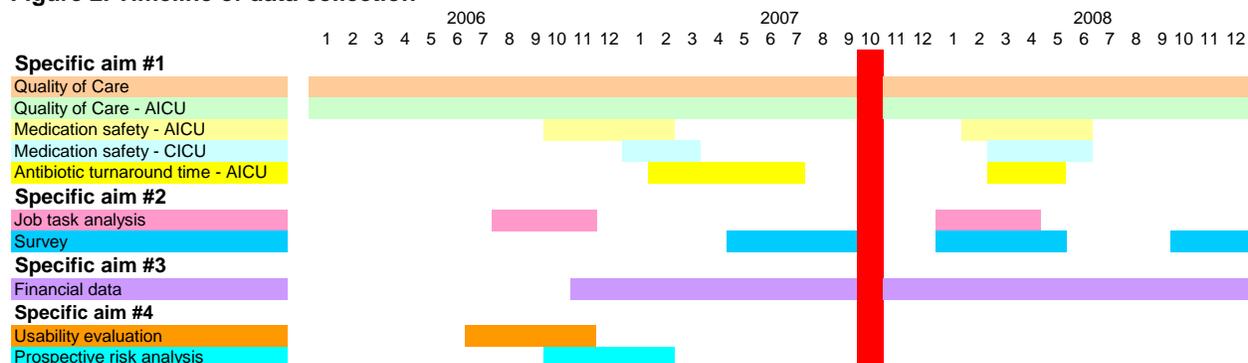
The CPOE/EHR was implemented in a phased manner, with each phase introduced to all four ICUs (and the rest of the hospital, including the ED and ORs) at the same time. The first phase provided test results (lab, radiology, cardiology, and others), radiology images, and secure e-messaging among clinicians; it was available by June 2002. The second phase, nursing documentation, was completed in June 2005. The third phase, including order management (order entry by clinicians, pharmacist processing, and administration documentation by nurses) and documentation by physicians and mid-level providers went live in October 2007. This is the implementation that was studied in this project.

Prior to implementation, the CPOE/EHR was customized for every unit and group of clinicians. This was particularly relevant in the ICUs, where interventions such as ventilators, central lines, and total parenteral nutrition (TPN) are more commonplace than elsewhere in the hospital. In addition, the CPOE/EHR included information-display tools designed specifically to provide coherent views of the complex data typically generated in the care of ICU patients.

### **Data Collection and Analyses**

Figure 2 shows the timeline of data collection for each of the specific aims and the intervention implementation date (red line, October 2007).

**Figure 2. Timeline of data collection**



## Specific Aim 1

**Medication Safety.** Data on medication errors and adverse drug events (ADEs) were collected in the Adult and Cardiac ICUs of GMC from October 2006 to March 2007 (pre-implementation) and March 2008 to June 2008 (post-implementation). These medication safety data describe errors and ADEs in the context of patient care, and include information on error interception and recovery, and the harm experienced by the patient or the potential harm. Because of the data complexity and the need to access protected health information (PHI), nurse data collectors (NDCs) were hired at Geisinger to gather information from patient charts and the EHR and transmit a limited data set to UW-Madison researchers. For the period the patient was in the ICU, the NDCs reviewed all medication orders in the patient chart; transcribed orders in the pharmacy system (for the pre-implementation period); documented medication administrations on the medication administration record (MAR); missing dose reports sent by the nurses to alert the pharmacy; laboratory, medication and patient symptom triggers potentially associated with adverse drug events; incident reports filed with the hospital reporting system; and events reported to the research team by clinicians. In the post-implementation period, reports were created from the EHR to aid in the review of several types of patient records. An iterative process of quality control and data clarifications followed. Two types of data adjudication were required because errors and ADEs are context specific and clinical judgment can vary. Adjudication of errors was completed by two researchers, and adjudication of harm is being completed by two critical care fellows and a senior internal medicine resident from UW Hospital. Analyses of the medication safety data include comparisons of the rates and types of errors and ADEs that occurred before and after CPOE/EHR implementation.

**Quality of Care.** The Quality of Care measures are monthly data series, which were regularly compiled at GMC. The data series collected for each ICU were unstandardized mortality rate and length of stay. For the Adult ICU and the Cardiac ICU, two additional data series were collected: ventilator-associated pneumonia and blood stream infections related to central catheter use. Several additional data series were collected in the Adult ICU: urinary tract infections, ventilator bundle compliance, self-extubations and percent reintubations, pressure ulcers and skin erosion, percentage of antibiotics given in one hour or less, and compliance with sepsis treatment guidelines. Data on standardized mortality rate and length of stay were collected only in the Pediatric ICU. Unless the data were unavailable, the months of data collected for each

series were January 2006 to December 2008, providing 21 months before CPOE/EHR implementation in October 2007 and 14 months after implementation. Preliminary analyses involved visual examination of the temporal trends; time-series analyses are in process.

**Antibiotic Turnaround Time.** The timeliness of antibiotic medication administration has been identified as a key process measure that has major impact on mortality of ICU patients (Kumar, et al., 2006). Antibiotic Turnaround Time (time between ordering an IV antibiotic and administering the medication) data were collected for first dose IV antibiotics ordered in the Adult ICU in the periods February to July 2007 (pre-implementation) and March to May 2008 (post-implementation). Specifically, the data collected include the dates and times of key steps in the medication use process: ordering of the medication, order clarification by the pharmacist, pharmacy processing, dispensing and administration. In the pre-implementation, a nurse data collector recorded data from the patient's paper chart and the pharmacy system. In the post-implementation, a report was generated from the EHR, appropriate orders were selected and deidentified by the nurse data collector, and data were sent to the UW-Madison research team. Analyses consisted of comparing the duration of the total medication use process (ordering to administration) and sub-processes before and after technology implementation, as well as examining the patterns in which the steps of the process were performed.

## Specific Aim 2

**Job Task Analysis.** Pre-implementation job task data were collected from August to November 2006 by performing observations of care providers in the four ICUs. The data collection method consisted of real-time observations performed by researchers who documented the activities of nurses and physicians using an electronic logging tool on a portable computer. The tool was initially developed by researchers at Vanderbilt and further refined by the UW-Madison research team (Schultz, et al., 2006). Observers followed a subject for approximately three hours and recorded every task performed and its duration, for a total of 330 hours of observations prior to implementation and 325 hours afterward. Observations were conducted of attending physicians, physician assistants (PAs), residents and nurses. For the post-implementation, task definitions were changed as necessary to fit the new CPOE/EHR technology, and observation data were collected from January to March 2008. Descriptive analyses examine the distribution of time among tasks, the average duration of tasks and hourly rates of tasks occurrence.

**Employee Questionnaire Survey.** Researchers created a questionnaire survey to examine CPOE/EHR implementation and usability and the effects of CPOE/EHR implementation on communication, coordination, quality of working life, and perceptions of patient safety and the quality of care. The survey was comprised of reliable and valid questions previously used to study technology implementation and the work of inpatient providers (Chin, Diehl, & Norman, 1998; Lee, Teich, Spurr, & Bates, 1996). Survey data were first collected from March to September 2007, prior to CPOE/EHR implementation. Paper surveys were handed to nurses, physicians and mid-level providers in all four of the ICUs and were returned to locked mailboxes on the units. In an attempt to reach more physicians, a web-based system was also used to distribute surveys in round 1, but technical difficulties in the email system made accessing the survey difficult. The second and third rounds of survey data were collected three months and

twelve months after implementation, from January to February 2008 and October 2008. Only paper surveys were distributed in these rounds. Surveys were distributed for several additional months (March-June 2008 and November-December 2008) to reach a sufficient number of residents on ICU rotations. Analyses of the survey data have examined acceptance of the CPOE/EHR technology and communication and coordination in the ICUs.

### **Specific Aim 3**

**Financial Analysis.** Monthly financial data, specifically the total costs of laboratory work, pharmaceuticals, radiology, transfusions and other treatment for patients in each ICU, were compiled by GMC for the period from November 2006 to December 2008. Also, we received data on the average productivity (in relative value units) of physicians in the Adult ICU from July 2006 to December 2008. The analyses involved visual examination of the data series to look for differences between the pre- and post-implementation periods. Additional analyses using time-series analysis are underway.

### **Specific Aim 4**

**Usability.** Usability Coordinator training began in August 2006 with a two-day training session for 17 Information Technology Department staff members and Geisinger Health System staff who interact with community providers. For more information on the usability training, please see the website at: [http://cqpi.engr.wisc.edu/cpoe\\_usability](http://cqpi.engr.wisc.edu/cpoe_usability). The training included an interactive lecture on design principles and heuristic evaluations of the electronic medication administration record (eMAR). Participants developed recommendations, which were grouped and prioritized for sharing with the software vendor. Another two-day training session on scenario-based testing was offered in October 2006 for 19 participants. The “hear, see, do” training session was followed by scenario-based testing with future users of the CPOE/EHR technology. The results were discussed and prioritized.

**Proactive Risk Assessment (PRA).** A proactive risk assessment (PRA) included a three-month planning period that led to an intense, five-hour session conducted on February 8, 2007. Nineteen individuals participated in the team portion of the PRA that included unit desk clerks, nursing staff, an informatician and educators, physicians and the IT design team. The participants addressed the issue of how documentation would be recorded and conveyed for patients being transferred directly to an ICU after surgery. Issues of usability were incorporated in the PRA because a key anticipated issue related to the amount and type of information to be recorded electronically. An exhaustive list of issues was identified, grouped, prioritized and shared with hospital and IT leaders, who then determined how to address the issues.

## Results

For most parts of this project, detailed analyses have been completed that could not be included in this report due to space constraints. Contact the research team for more information or see the website of the project at: [http://cqpi.engr.wisc.edu/cpoe\\_home](http://cqpi.engr.wisc.edu/cpoe_home).

### Specific Aim 1: Principal Findings

**Medication Safety.** The results of the Medication Safety analyses can be found in Table 4. After CPOE/EHR implementation, fewer medications were ordered on average in the AICU and the CICU. However, the number of adverse drug events per patient-day significantly increased in both units. Adverse drug events related to a medication error (preventable ADEs) significantly increased after implementation as well, but only in the AICU. However, these differences were likely related to the greater ease in identifying hypoglycemia events in the EHR system by the research team. An analysis excluding hypoglycemia events shows no significant differences between the pre- and post-implementation data on ADEs. Notably, the number of medication errors overall did not change in either unit; however, there were significant changes in the patterns of error types. For instance, the number and percentage of duplicate orders increased after the CPOE/EHR implementation whereas transcription errors were eliminated.

**Table 4. Descriptive findings on patients, medication errors and adverse drug events**

	AICU: Pre	AICU: Post	CICU: Pre	CICU: Post	Total: Pre	Total: Post
# patients/admissions	304	300	326	325	630	625
Age in years: mean, $\pm$ SD	58.9 $\pm$ 17.7	59.6 $\pm$ 17.9	63.8 $\pm$ 13.5	65.8 $\pm$ 14.3	61.4 $\pm$ 15.8	62.8 $\pm$ 16.4
ICU length of stay in days: mean, $\pm$ SD, range	8.7 $\pm$ 9.3, 1-67	8.1 $\pm$ 10.0, 1-87	4.6 $\pm$ 4.0, 1-35	4.9 $\pm$ 5.2, 1-49	6.6 $\pm$ 7.4, 1-67	6.4 $\pm$ 8.1, 1-87
Study period in days	119	113	72	81	191	194
Patient-days	2643	2430	1504	1583	4147	4013
Medication orders	27817	18668	17841	14173	45658	32841
Orders/pt day: mean, $\pm$ SD	<b>11.4</b> $\pm$ 4.4	<b>9.8</b> $\pm$ 5.8	<b>12.4</b> $\pm$ 5.0	<b>9.4</b> $\pm$ 5.0	<b>11.9</b> $\pm$ 4.8	<b>9.6</b> $\pm$ 5.4
Orders/admission: mean, $\pm$ SD	<b>91.5</b> $\pm$ 88.0	<b>62.2</b> $\pm$ 56.2	<b>54.7</b> $\pm$ 46.8	<b>43.6</b> $\pm$ 41.4	<b>72.5</b> $\pm$ 72.1	<b>52.5</b> $\pm$ 49.9
# of events (mean events/pt day $\pm$ SD)	1121 (0.4 $\pm$ 0.5)	1194 (0.5 $\pm$ 0.6)	629 (0.4 $\pm$ 0.6)	692 (0.4 $\pm$ 0.8)	1750 (0.4 $\pm$ 0.6)	1886 (0.5 $\pm$ 0.7)
# of errors (mean errors/pt day $\pm$ SD)	1315 (0.5 $\pm$ 0.6)	1314 (0.5 $\pm$ 0.7)	748 (0.5 $\pm$ 0.7)	756 (0.5 $\pm$ 0.8)	2063 (0.5 $\pm$ 0.7)	2070 (0.5 $\pm$ 0.8)
# of ADEs (mean ADEs/pt day $\pm$ SD)	85 ( <b>0.03</b> $\pm$ 0.08)	208 ( <b>0.08</b> $\pm$ 0.2)	42 ( <b>0.03</b> $\pm$ 0.08)	87 ( <b>0.05</b> $\pm$ 0.2)	127 ( <b>0.03</b> $\pm$ 0.08)	295 ( <b>0.07</b> $\pm$ 0.2)
# of preventable ADEs (mean/pt day $\pm$ SD)	41 ( <b>0.02</b> $\pm$ 0.05)	80 ( <b>0.03</b> $\pm$ 0.08)	20 (0.01 $\pm$ 0.06)	34 (0.02 $\pm$ 0.08)	61 ( <b>0.01</b> $\pm$ 0.06)	114 ( <b>0.03</b> $\pm$ 0.08)

Bold indicates significant differences between the pre-implementation and post-implementation.

**Quality of Care.** Visual evaluation of the temporal quality of care data shows no differences in most quality of care indicators after CPOE/EHR implementation. One exception is a consistent increase in the length of stay in the Neonatal ICU, but the change has been attributed to the addition of a new maternal fetal medicine specialist and a less healthy patient mix as a consequence. Also in the AICU, the rate of ventilator-associated pneumonia declined after implementation, and the rate of compliance with the sepsis resuscitation order “bundle” declined in the 6.5 months after CPOE implementation. Unfortunately, we do not have data on the latter measure after May 2008, which would indicate if the compliance rates have returned to pre-implementation levels. Additional analyses using time-series analysis are underway.

**Antibiotic Turnaround Time.** In the Adult ICU, data were collected on 79 pre-implementation orders and 202 post-implementation orders. Orders were excluded from the analyses if the antibiotic was ordered within 30 minutes of another IV antibiotic or medication administration was delayed until after a procedure (39 cases in the pre and 47 cases in the post). Results show that the duration from ordering to administration declined significantly after the CPOE/EHR implementation, primarily because of a reduction in the time from ordering to pharmacy processing (see table 5).

**Table 5. Antibiotic turnaround times before and after CPOE/EHR implementation (hours:minutes)**

	Pre-impl: Mean (SD)	Pre-impl: Median	Pre-impl: N	Post-Impl: Mean (SD)	Post-Impl: Median	Post-Impl: N
Ordering to administration	2:09 (1:49)	<b>1:40</b>	78	1:39 (1:47)	<b>1:04</b>	202
Ordering to pharmacy processing	0:55 (1:57)	<b>0:28</b>	79	7:53 (1:13:47)	<b>0:05</b>	181
Pharmacy processing to administration	1:42 (1:35)	1:17	71	1:31 (1:36)	0:57	171

Bold indicates pre-post differences are significant at  $p < .05$  (Mann-Whitney Us).

## Specific Aim 1: Discussion

CPOE/EHR implementation appears to have had a weak mixed effect on safety and quality of care in ICUs. For the majority of quality of care and safety indicators, CPOE/EHR implementation had no effect: the rate of medication errors per patient-day, mortality rates, length of stay, catheter-related bloodstream infections, self-extubations and several other measures of quality of care did not change after the CPOE/EHR implementation. However in the AICU, two important quality of care indicators improved: the rate of ventilator-associated pneumonia, and efficiency of IV antibiotic delivery.

## Specific Aim 1: Conclusions and Significance

The CPOE/EHR implementation does seem to have a negative impact on medication safety; however, with the implementation of CPOE/EHR new medication errors are emerging. Ongoing analysis of those medication errors and adverse drug events and their patient-related harm (either actual harm or potential harm) will help us to understand the impact of CPOE/EHR

implementation on patients. The CPOE/EHR implementation did not have any impact on quality of care, except for a strong positive impact on the timeliness of antibiotic medication delivery.

## Specific Aim 2: Principal Findings

**Job Task Analysis.** The results of the job task analyses for nurses, physicians and PAs can be found in tables 6 to 8. Tasks were classified into four categories: (1) conversational (including speaking with nurses, physicians, other clinical and support staff, patients and their families and listening to the conversation of others), (2) review and documentation tasks (reviewing and documenting in the patient chart, nursing documentation records, the medication administration record, administrative documents and personal notes), (3) direct care tasks (assessment of the patient, performing procedures, observing the patient, adjusting monitoring and other equipment, transporting the patient, and obtaining and administering medications), and (4) non-clinical tasks (gathering supplies, housekeeping tasks, waiting between tasks, walking to a new location, transporting equipment, searching for something, attending lectures or reading educational materials). Table 6 shows the percent of the total time spent performing the tasks in each category. Results show that after CPOE/EHR implementation, nurses spent significantly less time in conversation and more time in non-clinical tasks. A more detailed examination shows that nurses spent more time in manual tasks such as housekeeping, working with supplies and “running errands.” Physicians and PAs spent significantly more time reviewing and documenting information, and less time in all types of non-clinical tasks.

**Table 6. Duration of tasks as a percentage of total time**

	<b>Nurses: Pre</b>	<b>Nurses: Post</b>	<b>Physicians and PAs: Pre</b>	<b>Physicians and PAs: Post</b>
Conversational Tasks	32.35	28.06	46.46	43.39
Review and Documentation Tasks	24.32	26.49	<b>35.88</b>	<b>42.25</b>
Direct Care Tasks	25.97	24.54	6.88	6.90
Non-Clinical Tasks	<b>17.37</b>	<b>20.91</b>	<b>10.77</b>	<b>7.47</b>
Total	100.00%	100.00%	100.00%	100.00%

Bold indicates pre-post differences are significant at  $p < 0.05$ . Underline indicates significant differences at  $p < .10$ .

Table 7 describes the rate of activity occurrence per hour in each of the task categories, i.e. the number of activities recorded per hour. After CPOE/EHR implementation, both nurses and physicians and PAs performed more activities per hour in many categories, as well as overall.

**Table 7. Rate of activity occurrence [hourly rate]**

	<b>Nurses: Pre</b>	<b>Nurses: Post</b>	<b>Physicians and PAs: Pre</b>	<b>Physicians and PAs: Post</b>
Conversational Tasks	<b>34.38</b>	<b>46.61</b>	69.8	62.21
Review and Documentation Tasks	<b>27.08</b>	<b>52.03</b>	<b>57.9</b>	<b>88.4</b>
Direct Care Tasks	<b>40.70</b>	<b>62.72</b>	15.21	13.68
Non-Clinical Tasks	<b>33.70</b>	<b>58.21</b>	<b>28.06</b>	<b>19.76</b>
Total	<b>135.86</b>	<b>219.56</b>	<b>170.91</b>	<b>184.05</b>

Bold indicates pre-post differences are significant at  $p < 0.05$ .

Table 8 shows the average duration of activities in each category. For nurses, all types of tasks became significantly shorter after CPOE/EHR implementation. The duration of tasks for physicians and PAs also became shorter overall, though the difference was only significant in the category of review/documentation tasks.

**Table 8. Mean duration of activities, in seconds**

	<b>Nurses: Pre</b>	<b>Nurses: Post</b>	<b>Physicians and PAs: Pre</b>	<b>Physicians and PAs: Post</b>
Conversational Tasks	<b>26.60</b>	<b>21.52</b>	28.89	29.24
Review and Documentation Tasks	<b>23.47</b>	<b>18.95</b>	<u>29.01</u>	<u>24.60</u>
Direct Care Tasks	<b>17.98</b>	<b>14.44</b>	18.55	17.64
Non-Clinical Tasks	<b>15.50</b>	<b>13.32</b>	16.81	14.38
Total	<b>20.49</b>	<b>16.69</b>	24.29	21.91

Bold indicates pre-post differences are significant at  $p < 0.05$ . Underline indicates significant differences at  $p < .10$ .

**Survey.** The combined response rate for the employee questionnaire survey was 61% overall, 72% for nurses and 45% for physicians and mid-level providers (PAs and NPs). Results show that ICU nurses had significantly less experience than providers in working with computers or with the CPOE/EHR technology in outpatient clinics. In round 2, 13% of nurses had less than two years of computer experience and 80% had very little experience with CPOE/EHR, compared to 4% of providers that had equally low levels of computer experience and 17% with equally little CPOE experience. Ordering providers were also much more likely than nurses to be involved in pre-implementation planning activities, with 65% of providers involved in one or more activities and 29% of nurses similarly involved. Perhaps consequently, providers rated the information that they received about the implementation and the quality of their own inputs into the implementation process significantly more positively than nurses.

Table 9 shows the results of the analyses on acceptance of CPOE/EHR technology and several of its key components at 3 months and 12 months after the implementation. Nurses became more accepting of the technology between the two waves of data collection, while providers came to view the technology less positively. At 12 months, the two groups had nearly identical moderately positive views of the technology. Partly because of the larger sample sizes, significant over-time differences are more often found for nurses, whose views of EHR usability and the perceived functionalities of the CPOE and electronic medication administration record (eMAR) improved. Providers came to view the functionality of the nursing flowsheet less positively over time.

**Table 9. Analyses of CPOE/EHR acceptance (mean, SD)**

	<b>Nurses: 3 months</b>	<b>Nurses: 12 months</b>	<b>Providers: 3 months</b>	<b>Providers: 12 months</b>
Acceptance of EHR technology: Dislike very much and don't want to use (1) – Like very much and eager to use (10)	<b>6.32</b> (2.33)	<b>6.91</b> (2.15)	<b>7.58</b> (1.61)	<b>6.92</b> (2.18)
EHR usability*	<b>48.95</b> (20.89)	<b>56.41</b> (20.55)	55.44 (21.27)	48.31 (24.21)
Perceived functionality of eMAR*	<b>64.01</b> (25.91)	<b>70.99</b> (22.33)	65.53 (22.59)	59.64 (26.51)
Perceived functionality of CPOE*	<b>48.08</b> (24.07)	<b>56.34</b> (24.14)	60.29 (23.43)	54.09 (25.67)

Perceived functionality of nursing flowsheet*	66.62 (23.81)	70.37 (22.50)	<b>65.03</b> (22.99)	<b>59.94</b> (26.91)
N	121	160	53	52

\* These measures are scales combining 2 to 8 items and range from 1 (low) to 100 (high).

Bold indicates pre-post differences are significant at  $p < 0.05$

Regression analyses (not shown) were performed to predict acceptance of the EHR technology. Separate models were run for nurses and providers in each of the two follow-up rounds (i.e. 3 months and 12 months post CPOE/EHR implementation). Results show that computer experience predicts acceptance for nurses at 12 months after implementation and providers at 3 months after implementation. EHR usability predicted acceptance for nurses in both rounds and for providers at 3 months. The perceived functionalities of CPOE, eMAR and nursing flowsheet predicted acceptance for nurses (at 12 months, 12 months and 3 months respectively), but not for providers. The providers' model shows that attendings were more accepting of the technology at 12 months than residents and PAs/NPs, perhaps because they spent less of their time entering orders. Notably, the variance explained by the providers' model at 12 months was substantially lower (adjusted  $R^2=.40$ ) than for the nurses' 12 months model (adjusted  $R^2=.69$ ).

Other descriptive analyses were performed examining the effect of CPOE/EHR on communication, coordination, perceptions of quality of care and patient safety in the ICUs. Analyses showed no changes in communication and coordination, except for perceptions of decreased communication timeliness 3 months after implementation. By one year after implementation, perceived timeliness had returned to the baseline level. Similarly, perceived quality of care and patient safety declined at 3 months and returned to baseline levels by 12 months.

## Specific Aim 2: Discussion

The implementation of CPOE/EHR had several effects on end users and their work. The Job Task Analysis shows that the work of nurses and physicians/PAs changed in several important ways. After the CPOE/EHR implementation, nurses spent less time in conversation and more time doing manual tasks. They also performed review/documentation tasks and non-clinical tasks more often. The duration of each task performed became shorter, declining from an average of 20 seconds to 17 seconds. One outcome of the data collection method is that an interrupted task appears in the data as two or more shorter tasks. Thus, the findings for nurses may indicate that their tasks became interrupted more often after implementation. The work of physicians and PAs also changed, as they spent more time reviewing and documenting information and less time in clinical tasks. Their conversational and non-clinical tasks became less frequent, while review and documentation tasks became more frequent and shorter; therefore, suggesting that these tasks were more often interrupted.

The results of the employee questionnaire survey show that, compared to physicians and other ordering providers, nurses felt less positively about the technology and its components at 3 months after implementation. However, their views of the technology improved over time, while providers' views became less positive over the next 9 months. Regression models predicting providers' acceptance of the technology at 12 months showed that attendings had significantly more positive views of the technology than residents and PAs. Also, the 12-month providers'

model accounts for less of the variance than the nurses' model, indicating that the predictors (computer experience, unit, EHR usability and the perceived functionalities of CPOE, eMAR and the nursing flowsheet) explained providers' views of the technology less well.

Notably, the survey results show that declines in perceived communication timeliness, patient safety and quality of care were all short lived, returning to pre-implementation levels at 12 months after implementation. This finding suggests that the ICU staff were able to adapt to the new technology in a relatively short period of time.

## **Specific Aim 2: Conclusions and Significance**

The observational data collected on tasks performed by ICU nurses, physicians and PAs show some major changes in time spent, in particular increased time spent on documentation and review tasks. In addition, there seems to be a trend towards shorter activity duration and greater hourly rate of activities. These changes in the structure of the job tasks were not accompanied by changes in perceptions as measured by the survey. The CPOE/EHR implementation produced short-term negative impact on ICU staff perceptions of communication timeliness and quality and safety of care; however, these negative effects disappeared after 12 months.

## **Specific Aim 3: Principal Findings**

Like the analyses for the quality of care measures, we performed a visual evaluation of the temporal financial data. No differences in the patterns of ICU costs or physician productivity were found after the implementation of CPOE/EHR.

## **Specific Aim 3: Discussion**

These results show that CPOE/EHR did not affect ICU costs in the 14 months after implementation.

## **Specific Aim 3: Conclusions and Significance**

There was no change in the financial data after the CPOE/EHR implementation.

## **Specific Aim 4: Principal Findings**

**Usability.** The principal means of assessing the effectiveness and usefulness of usability coordinator training was obtained through feedback provided immediately post-training by the participants. Responses to survey questions were based on 5-point Likert scales (e.g., 1 = poor; 5 = excellent). See Table 10 for the survey response summaries.

**Table 10. Evaluation of usability training**

	<b>Usefulness of training</b>	<b>Quality of training</b>	<b>Confidence to conduct independently</b>	<b>Ability to incorporate in work</b>	<b>Comfort sharing with others</b>
Training session I (N=16)	Mean = 4.6	Mean = 4.7	Mean = 4.3	Mean = 4.1	Mean = 4.1
Training session I (N=16)	Median = 5	Median = 5	Median = 4.5	Median = 4	Median = 4
Training session II (N=18)	Mean = 4.1	Mean = 4.1	Mean = 4.1	Mean = 3.5	Mean = 3.8
Training session II (N=18)	Median = 4	Median = 4	Median = 4	Median = 3.5	Median = 4

**Proactive Risk Assessment (PRA).** Fifty-nine issues were identified during the team phase of the PRA: 40 of the issues were grouped and resulted in 22 relevant issues that were later prioritized; 16 were deemed to be out of the scope of the PRA but related to other aspects of IT design and workflow (and were forwarded to the appropriate IT staff for action and/or consideration); and the remaining 3 were determined by the group to be irrelevant. The 22 pertinent issues were then prioritized using a taxonomy unique to, but understood by, workers of the organization. Three of these 22 were identified as “regulatory” (accrediting or legislative in nature) issues and of high or medium concern from a patient safety, quality of care and medical-legal perspectives. Recommendations for resolving the key issues included: 1) providing the unit clerk with an electronic template for monitoring orders and other activities they were accustomed to monitor pre-CPOE/EHR implementation; 2) addressing, through the design of the software and its interface, when the physician orders should be “released”, and thus be acted upon; 3) determining how to design the software so “discharge all” orders identified the need to update the respective code status of a patient; and 4) providing an electronic template for providers to use for conveying relevant information.

Participant feedback on the team portion of the PRA was captured at the end of the meeting through a questionnaire. Thirteen of the 19 participants completed the questionnaire. Using a 5-point Likert scale (1=completely useless, 5=extremely useful; 1=not at all willing, 5=extremely willing), respondents rated the usefulness of the PRA (mean = 4.2) and their willingness to participate in a future PRA (mean = 4.3).

In a follow-up meeting of IT leaders and analysts working on the CPOE/EHR interface, positive comments were shared related to the high degree of participation by everyone involved in the team phase of the PRA and high satisfaction with the number and type of issues identified.

## **Specific Aim 4: Discussion**

The impact of both prospective human factors analysis methods employed in this research demonstrated good “fit” with the organization’s ongoing commitment to user-friendly CPOE/EHR interface design and improvements in workflow that correspond with technology implementation. Both methods (usability and PRA) are now common practice at the organization. A usability evaluation stage is a standard portion of all health IT design and implementation. Likewise the value of PRA applied to health IT design and implementation has been demonstrated to the satisfaction of organizational leadership. Previous less focused PRAs were informal and generally included homogenous groups who convened to identify issues specific to their practice. By convening a heterogeneous group of interdependent users, the organization now believes issues of greater breadth and depth are identified, prioritized, and dealt with through the IT design and implementation processes.

## **Specific Aim 4: Conclusions and Significance**

This work clearly demonstrates the value of formal usability training for individuals creating the CPOE/EHR interface. Similarly, conducting a proactive risk assessment prior to technology implementation is critical and can, and in this case did, address both workflow and interface design issues.

## **Overall Conclusions**

Future research should focus on the longitudinal use of CPOE/EHR technology. This research can help in identifying ways that the technology can be used for improving work systems, care processes, and quality of care and patient safety. Issues related to end user adaptation of and to the technology are also important to examine in future longitudinal research.

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## List of Publications and Products

### Publications

- Carayon, P., Faye, H., Hundt, A. S., Karsh, B.-T., & Wetterneck, T. (2009). Patient safety and proactive risk assessment. In Y. Yuehwern (Ed.), *Handbook of Healthcare Delivery Systems*: Taylor & Francis.
- Carayon, P., & Wood, K. E. (2009). Patient safety: The role of human factors and systems engineering. In W. B. Rouse & D. A. Cortese (Eds.), *Engineering the System of Healthcare Delivery*: IOS Press.
- Djurkovic, S., Cartmill, R.S., Blosky, M.A., Dunham, D., Gardill, D., Haupt, M., Parry, D., Walker, J.M., Wetterneck, T.B., Wood, K.E. & Carayon, P. (2009) "CPOE implementation decreases the time to the administration of the first dose of antibiotic," abstract accepted for presentation at the 2010 Society for Critical Care Medicine conference.
- Hoonakker, P.L.T. & Carayon, P. (2007). Selection of an instrument to measure end-user satisfaction. Paper presented at the Work with Computing Systems (WWCS) 2007 Conference, Stockholm, Sweden, May 21-24, 2007.
- Hoonakker, P.L.T., Carayon, P., Douglas, S., Schulz, K., Walker, J., & Wetterneck, T.B., (2008). Communication in Intensive Care Units and the Relation with Quality of Care and Patient Safety from a Nurse Perspective. *Human Factors in Organizational Design and Management - IX*, edited by Szelwar, Mascia & Montedo. Santa Monica, CA: IEA Press, pp. 715-721.
- Hoonakker, P.L.T., Carayon, P. & Walker, J. (2008). Evaluation of CPOE Implementation: Measuring end-user satisfaction with a survey questionnaire. To be submitted to *Journal of Biomedical Informatics*.
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## Products

Three products were created while completing the research for this grant:

1. The data logger tool used to collect real-time job task data for physicians and nurses (Schultz et al. 2006).
2. The employee survey questionnaire used to assess perceptions of physicians, mid-level providers and nurses in the ICUs in the following areas: CPOE/EHR implementation and usability and the effects of CPOE/EHR implementation on communication, coordination, quality of working life, and perceptions of patient safety and the quality of care (Hoonakker, Carayon and Walker 2008).
3. The database used to collect the medication safety data on medication errors and adverse drug events (Paris, Carayon et al 2008; Wetterneck, Paris, Blosky et al. 2008).