Analysis of Patient Safety: Converting Complex Pediatric Chemotherapy Ordering Processes from Paper to Electronic Systems

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Abstract

Objective: The objective of this project was to evaluate the risks associated with converting a paper-based pediatric chemotherapy ordering process to a fully electronic system. **Methods:** Formal process redesign and systems analysis, primarily through Failure Mode and Effects Analysis (FMEA), was used to evaluate the current, paper-based chemotherapy medications process. A commercial software system designed to accomplish computerized provider order entry (CPOE), safety checks, pharmacy dispensing, and medication administration documentation were examined to determine whether these integrated applications are as safe as a paper process with multiple redundant checks. **Results:** Formal process redesign and system analysis methods uncovered important potential failure points within the integration points of the electronic system. **Conclusion:** Prospective, institution-specific process redesign and system analysis is a valuable tool for determining the safety and feasibility of converting complex medication ordering processes from paper to electronic systems. Commercially available CPOE systems may not be immediately capable of safely executing complex chemotherapy regimens.

Introduction

Various technologies exist to increase patient safety associated with medication use. The entry of medical orders by clinicians directly into computerized electronic medical record systems (computerized provider order entry, CPOE) has been touted as a key method to reduce medication errors and adverse drug events. Influential entities, such as The Leapfrog Group, have encouraged the adoption of CPOE as a means of reducing errors.[1] Furthermore, in its 2007 report "Preventing Medication Errors," the Institute of Medicine (IOM) recommended that all prescriptions be written electronically by 2010.[2] Most health care professionals concur that CPOE eliminates errors caused by illegible handwriting, and the technology is capable of substantially improving the medication use process through clinical decision support. However, implementing CPOE is challenging, particularly for high-risk processes, such as chemotherapy administration.

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Many hospitals are working to implement electronic ordering systems, but few (approximately 5 percent) have broadly implemented true CPOE, and only a very small percentage employ CPOE for complex chemotherapy regimens.[3, 4, 5] Two recent systematic reviews revealed a dearth of high quality studies substantiating enhanced patient safety through CPOE. In particular, these reviews noted that most of the studies demonstrating benefits of CPOE were conducted at four health care systems that developed their own "homegrown" order entry applications and customized these applications over time to meet the specific needs of their institutions.[6, 7]

Recently, the unintended consequences of CPOE, including descriptions of new errors brought about by CPOE, have been characterized.[8, 9, 10] These negative studies have generated substantial concern, particularly in pediatric settings. Walsh and colleagues demonstrated that CPOE does introduce new kinds of errors in pediatric patients, but they suggested that serious computer-related errors are rare.[11] Nonetheless, harm from CPOE could exist in complex pediatric patient care areas. The introduction of CPOE in a pediatric intensive care unit was associated with an increase in mortality.[12] However, the shortcomings of CPOE identified in this publication were not intrinsic to CPOE, but rather, they were consequences of the process-redesign and implementation tactics.[13] This observation demonstrates that the implementation process is crucial to realizing the safety benefits associated with CPOE.

It is incumbent on clinical and administrative leaders of health care organizations to be certain that all aspects of CPOE and other electronic health records systems are at least as safe, if not more safe, than current practices, especially in high-risk areas of patient care, such as chemotherapy administration. For over 45 years, our institution has focused on maximizing the safety of the paper-based ordering system for chemotherapy medications in children. Therefore, we are particularly concerned about the comparative safety of the electronic ordering system for this critical process. To prospectively assure the safety of CPOE with regard to chemotherapy ordering and administration, a formal process redesign and systems analysis was conducted.

Methods

Formal process redesign methodology was utilized to define and evaluate the current paper-based processes and subprocesses associated with chemotherapy ordering practices at St. Jude Children's Research Hospital. Process flow maps outlined each step in the process, what role or resource accomplished each step, where each process ended and another began, and links between processes. Failure modes and effects analysis (FMEA) was used to assess how individual components of the chemotherapy ordering process could fail, how likely failure was, and the consequences of failure.[14]

A team consisting of individuals directly involved in chemotherapy administration processes was assembled: pediatric oncology physicians, nurse practitioners (NPs) and physician assistants (PAs), who generate chemotherapy orders; pharmacists and technicians, who receive, check, and transcribe orders and prepare and deliver chemotherapy; nurses, who receive, check, and carry out these orders, including administration of chemotherapy to patients; re-engineering analysts; quality improvement specialists; and informatics specialists, including a pharmacist/informatics specialist who led the team. To provide a mixture of experience levels, the team was composed

of staff members with several years of experience with the process as well as relatively new staff members.

Initial meetings with the entire team introduced the purpose of the project and provided education and training on the analytic method to be used, in addition to background information regarding previous efforts to analyze the chemotherapy process at St. Jude. The major components of the overall chemotherapy ordering process were identified and flow-charted.

Consensus was reached among team members that the overall process included three major subprocesses: (1) the clinician process of ordering the chemotherapy; (2) the pharmacy process of reviewing, processing, and dispensing the ordered medication; and (3) the nursing process of reviewing and carrying out the orders. Teams were then formed for each of the three major subprocesses. At minimum, subprocess teams included clinical practitioners directly involved in these processes on a daily basis, a re-engineering analyst, a quality improvement specialist, and an informatics specialist. Weekly 2-hour meetings were conducted to develop specific work-flow maps of the current state for each subprocess.

After flow-charting the three major process components, the full team reassembled to review and discuss the individual detailed processes and make any necessary modifications to the overall process-flow map. Upon reaching consensus on the overall process-flow map and individual detailed process-flow maps, each subprocess team reconvened to conduct the FMEA.

Each process step was evaluated for potential failure points, identifying the potential cause(s) and effect(s), and the detection method of the potential failure points. Potential failure points were scored by team members for severity (i.e., effect on the patient should failure occur); occurrence (i.e., an estimate of how often this potential failure might occur); and the likelihood of detecting a failure prior to completion of the process. A 10-point scale (0 = best, 10 = worst) was used to score severity, occurrence, and likelihood of detection. Each component score was then multiplied together to create a risk priority number (RPN). An RPN value >150 was used as a cutoff for further review and analysis.

To determine overall acceptability within the context of complex chemotherapy orders, available functions of the institution's electronic ordering application (Millennium PowerOrders®, Cerner Corporation, Kansas City, MO) were presented to team members. Two available strategies for generating electronic orders and one strategy under development by the software vendor were presented to clinicians who generate complex chemotherapy orders and nursing staff members who execute these orders. The two available strategies included (1) individually initiating each order for chemotherapy and associated medications, and (2) using an electronic care set that presents orders as a logical group to the ordering clinician but does not maintain the grouping after electronic signature. The future strategy planned by the software vendor presents orders together in logical groupings that are retained after signature and execution, and it provides the ability to develop time dependencies between orders.

Paper-Based Chemotherapy Medications Process Flow

The paper-based chemotherapy medications process flow was delineated by current state process flow meetings. After St. Jude's Central Protocol and Data Monitoring Office confirms clinical trial or single patient treatment plan enrollment, an oncologist must request a set of preprinted

order sheets developed specifically for that clinical trial or treatment plan and approved by the principal investigator of the trial or author of the plan. This preprinted order set is then placed into the patient's chart for current or future use. Before initiating any chemotherapy order regimen, the clinician is expected to review the protocol and the patient's medical record for all pertinent information. The clinician then executes the preprinted order set for the appropriate day or week of treatment, calculating and filling in each medication dosage and the expected date and time of treatment.

If a nonphysician or physician who lacks chemotherapy prescribing privileges generates these orders, the orders are available within the medical record for cosignature by a physician with chemotherapy prescribing privileges granted within the organization. The orders are reviewed by a nurse in the clinical area where the orders are generated to determine protocol compliance and to double-check all calculations. Orders might then remain in a holding state until close to the date/time for which treatment is scheduled. Before further action, to comply with the protocol, the patient's clinical status and any protocol-required laboratory tests or procedures must be confirmed by a chemotherapy-certified oncologist. Once it is assured that these key clinical requirements have been met, the oncologist generates an order within 24 hours of the scheduled chemotherapy administration time, indicating that it is now "OK to give" (i.e., acceptable to administer the planned chemotherapy regimen at the scheduled time).

After the nurse has performed the necessary safety checks, orders are faxed or delivered to receiving departments, primarily the pharmacy and infusion center within the hospital. Parallel processes then take place within these areas. These include further safety-related checks to assure protocol enrollment, protocol compliance of the planned treatment, correct timing of therapy, and correct dosage calculations. Both the pharmacy and the infusion center require independent checks by at least two licensed professionals (pharmacists for pharmacy, and nurses for the infusion center). The pharmacy process includes transcription of the orders into the pharmacy information system (Cerner Inpatient PharmNet®), which provides automated allergy and drug interaction warnings, prints labels to be affixed to the final dosage formulations, and facilitates medication preparation. Release of the medications by the pharmacy and delivery to the patient care area are accomplished only after confirming the receipt of the "OK to give" order.

The nursing process in the ambulatory infusion center includes (1) an initial review of the faxed or written orders, which often occurs prior to patient arrival and receipt of the patient's medical record; (2) receipt of the drug(s) from the pharmacy; (3) planning the intended treatment regimen; and (4) performing the dual safety checks referred to above. Drugs received from the pharmacy are compared against the orders and electronic medication administration record entries for drug name, dosage, diluent type and volume, and infusion duration. Before chemotherapy administration, a dual, independent verification of the patient's identity, using at least two methods (typically name and medical record number), is completed, and appropriate venous access is verified. Nurses administer the ordered chemotherapy and related medications, complete all necessary documentation within the electronic health record (PowerChart®, Cerner Corporation, Kansas City, MO), observe the patient, provide all necessary care during treatment, and finally, discharge the patient with appropriate education.

In summary, in the current paper-based system, the clinician ordering the chemotherapy regimen is expected to carefully compare the treatment regimen to be ordered with a reference document

and to scrupulously complete the order document, which comprises preprinted order sheets meticulously developed for consistency and safety reasons. Ordering is followed by redundant checks of the same information by at least three groups of health care professionals (a minimum of five individuals). Subprocesses include at least one redundant check to make certain that no individual completes his/her portion of the process without review.

Results

Proactive Evaluation of Proposed Process for Chemotherapy CPOE

Few steps of the current paper-based processes, which do not include CPOE, had RPN scores that reached a level requiring additional analysis (i.e., 150). The processes identified as requiring additional analysis are listed in Table 1.

Prior to conducting an FMEA of the proposed electronic ordering process, a proactive evaluation of the proposed process revealed important deficiencies in the integrated software applications in use at St. Jude. These deficiencies precluded immediate implementation of electronic prescribing for chemotherapy:

- Entry of individual orders one-by-one by clinicians was summarily dismissed as too time consuming and error-prone, compared with paper-based, preprinted orders currently in use.
- Electronic order sets were deemed unacceptable due to a system constraint within each order that required a specified date and time be established and completed by the end user.
- Complex chemotherapy regimens often have 10 to 20 individual component orders, some of which may need to be achieved in a critically timed sequence or time relationship with a single key component. Therefore, ordering clinicians determined that the risk of an error in dating and timing each order individually in the regimen sequence was too high, compared with the current paper-based process.
- An additional problem with electronic order sets was that upon electronic signature by the clinician, each order associated with the order set was distributed either to that order item's logical application (i.e., pharmacy, lab, radiology) or listed in the electronic health record under its category listing. In contrast to preprinted orders, this immediate distribution eliminated the context of the order set associated with the chemotherapy regimen, making pharmacists aware only of pharmacy orders, medical technologists aware only of lab orders, and clinicians and nurses unable to visualize the regimen (order set) again as it existed prior to clinician electronic signature.

Advanced ordering function, recently added to the vendor's software package (PowerPlans®), eliminated the deficiencies listed for individual order entry and electronic order sets. It also included features enabling predefined time-sequence relationships between orders commonly found in oncology (e.g., time 0, 1 hour after time 0, etc.). This functionality was evaluated

Table 1. Risk priority number (RPN) scores for components of the paper-based system for ordering, dispensing, and administering chemotherapy that exceeded 150[a]

Process	Component that warranted additional concern	RPN score
Ordering	Generating an "OK to give" order by a chemotherapy-certified physician, who did not obtain and review all required information. This requires a nononcologist provider to hold the order until the last piece of pertinent clinical data is available before transmitting the order to receiving departments (i.e., a conditional "OK to give" order).	360
Dispensing	Not recognizing that orders were transmitted with the incorrect patient name	420
	A problem with legibility associated with either handwriting or fax transmission	280
	An incorrect volume of diluent being used for reconstitution of a medication product	200
	A medication being injected into the incorrect admixture bag, if multiple products were being prepared at the same time	224
Administration	Infusion center nursing staff not recognizing premedications that were indicated but not ordered based upon previous adverse drug reactions	210
	The second infusion center nurse failing to check multiple patient identifiers	210
	The second infusion center nurse performing the required checks without recognizing an error	210
	The second infusion center nurse administering a medication by an incorrect route of administration	200
	The second infusion center nurse failing to provide patient followup	210

a A predetermined level deemed to warrant additional analysis.

further by attempting to recreate existing chemotherapy regimens electronically from preprinted order sheets currently in use. As described below, although team members considered these functionalities to be key advances, they also recognized important deficiencies in the software applications or in the integration points between them that again precluded the immediate implementation of electronic prescribing of chemotherapy.

Limitations that Prevented Implementation of CPOE for Chemotherapy

As summarized in Table 2, several important limitations did not allow further implementation of CPOE for chemotherapy. The clinician ordering application supports two types of electronic orders: (1) orders for single medications and (2) orders for intravenous (IV) fluids that are to be administered continuously at a prescribed rate. An evaluation of this software with actual oncology orders uncovered several issues. First, functionality to allow ordering of IV fluids that

Table 2. Summary of important limitations of current enhanced software for ordering chemotherapy and implications for patient safety

Limitation	Representative implication for safe provision of chemotherapy
Clinician ordering: System does not allow clinician to order some types of orders important to the safe delivery of chemotherapy (e.g., corresponding intravenous fluids).	Appropriate hydration is essential for the safe delivery of many complex chemotherapy regimens.
Integration: Types of orders in the clinician order entry and pharmacy sections of the system do not match.	Falls short of seamless integration of clinician ordering and pharmacy functions, which limits the pharmacist's ability to review and check chemotherapy.
Medication frequencies: The system does not support interval frequencies, such as Q3H x 3 doses/day.	Common frequencies used in chemotherapy regimens. If alternate frequencies were used, confusion and error would result.

are to be administered intermittently at a specified rate over a specified period and repeated at a specified interval was not available (e.g., 500 mL of D_5W prehydration for chemotherapy to be infused over a 4-hour period at a rate of 125 mL/hr and repeated daily for 5 days). Second, orders that are generated within chemotherapy regimens that consist of more than one medication to be administered together in one intravenous admixture bag also were not supported by the software design.

The pharmacy dispensing application is automatically populated by orders generated within the clinician ordering application, or it can be the initial electronic point of entry if orders are generated outside the system (i.e., written on paper). The pharmacy application supports three types of orders: (1) continuous IV fluids, (2) single medications, and (3) intermittent IV infusion orders (unlike the clinician ordering application). These intermittent orders (IV fluids, multiple IV drugs admixed in the same admixture bag, or single IV drugs) include an infusion rate, an amount of time over which to infuse each dose, and the frequency at which the infusion should be repeated.

This discrepancy between the clinician ordering application (two order types) and pharmacy application (three order types) results in deficiencies associated with integration points between the two applications. For example, an order for a chemotherapeutic agent could be created using the CPOE application's medication functionality with a defined time over which to infuse each dose and a defined interval to repeat dosing. This order automatically populated the pharmacy application, allowed the pharmacist to assign an appropriate medication product to meet the dispensing needs of the order, but it did not populate the "infuse over" field within the list of defined order details for each intermittent medication order. Instead, the "infuse over" field was either left blank or was populated with a value defaulted for that product from pharmacy reference values.

In addition, a shared feature of CPOE and pharmacy applications, the "frequency of administration" field, had a design deficiency that caused problems during testing.

The frequency application was designed to use interval frequencies (e.g., repeat dosing every x hours, days, or weeks) and defined the number of doses per day at specified time-of-day frequencies (e.g., BID, TID, QID). However, the system did not support interval frequencies, such as Q3H x 3 doses/day, where the first dose should begin at a specified date and time but limited the number of doses due within a 24-hour period to something less than the interval would equate to over 24 hours.

Discussion

Formal process redesign and system analysis has proved valuable to the implementation of CPOE at our institution. Our initial intent was to perform comparative FMEA of both the paper-based and proposed electronic chemotherapy ordering processes. However, our proactive approach identified significant shortcomings in the software enabling the ordering, dispensing, and administration of chemotherapy prescribed as part of complex regimens, which is a high-risk and high-volume process at our hospital. These shortcomings undermined our plans to perform an FMEA of the electronic ordering process and prompted us to collaborate with the vendor to improve the software system and eliminate identified deficiencies before further considering transition. If CPOE implementation for chemotherapy had continued without recognizing these issues, serous patient harm could have resulted. Our efforts have allowed us to act to correct potential difficulties before implementation, thereby mitigating harm to patients. We plan to conduct a comparative FMEA of the electronic ordering process as soon as a fully functional ordering application is developed.

Safe Use of Chemotherapy

Chemotherapy medications are, by design, highly toxic agents that typically have very narrow therapeutic windows. The difference between a dose that causes the desired effect (i.e., killing cancer cells) and a dose that causes undesired or toxic effects is often small. As the benefits of combination chemotherapy regimens have been realized, regimens used in a variety of malignancies have become more complex; increased complexity results in a higher risk of error and potential harm.

These complexities are somewhat amplified in pediatric oncology, where doses of chemotherapy drugs might change from week to week or month to month, based on changes in the child's body size. Risks associated with individual chemotherapy regimens can vary widely. Some regimens are relatively simple (e.g., single, low-dose methotrexate in acute lymphocytic leukemia regimens), but others are incredibly complex (e.g., multidrug, multiday regimens with corollary and supportive care).

Because of St. Jude's commitment to research, the vast majority of patients treated for pediatric cancers are enrolled in clinical trials. This helps make treatment regimens consistent across patients with specific diseases, reducing variability of care, and providing a reference for treatment to all health care providers. However, research regimens are often more complex than conventionally accepted "best practices," which further adds to the increased risk of harm and errors.

Like other major cancer and academic centers, St. Jude Children's Research Hospital devotes a tremendous amount of effort and resources to ensure that systems and processes associated with delivering chemotherapy regimens are safely designed and executed.[15] These systems and processes, listed in Table 3, have been refined and adjusted over the past 45 years to a point where serious errors rarely occur.

In 1997, St. Jude committed to convert patient medical records from the traditional pen-and-paper-based records to an integrated electronic health record, based on discrete data to the extent feasible. To achieve maximal integration, the institution elected to purchase applications from a single vendor that supported a wide range of clinical applications. A phased-in approach to installation of this suite of applications began in 1999 with implementation of an Oracle relational database and an application (PowerChart®) to view the laboratory information stored in this core database.

Table 3. Systems and processes associated with ordering, dispensing, and administration of chemotherapy

1.	Effective training and credentialing of staff to prescribe, dispense, and/or administer chemotherapy according to the staff member's role in patient care.
2.	The availability and use of clearly defined treatment plans (e.g., clinical trial document) within each patient's medical record.
3.	Clearly constructed, consistent, and carefully reviewed preprinted order sheets that are specific to the clinical trial or treatment plan.
4.	Elimination of the use of acronyms, brand names, or abbreviations of chemotherapy drugs.
5.	"Tall-man" lettering in both printed orders and electronic health record displays.
6.	Checks of prescriber's orders by nurses in the patient care area, where the orders originate, utilizing the treatment plan document as the reference prior to transmission to pharmacy and medication administration areas.
7.	Review of electronic order entry and dosage preparation by at least two pharmacists.
8.	Distinct labeling and packaging of chemotherapy drugs.
9.	A separate and distinct order by a physician with chemotherapy prescribing privileges to authorize the administration of chemotherapy regimens as ordered ("OK to give chemotherapy as ordered") before chemotherapy medications are delivered to the patient care area for administration.
10.	Checks of the prescriber's orders by at least two nurses in the patient care area where medication administration is to occur, with comparisons to the medications dispensed by the pharmacy.
11.	Separate and distinct patient care areas for administration of intrathecal antineoplastic medications, compared to medications to be administered by other routes.
12.	Independent positive patient identification by two nurses using at least two patient identifiers (e.g., medical record number and name, name and date of birth) prior to medication administration.
13.	Medication administration.
14.	Documentation of medication administration.
15.	Evaluation and documentation of patient response.

Since then, full implementation has been achieved with:

- Patient registration.
- Health information management.
- Patient scheduling integrated with CPOE.
- Research protocol management and enrollment.
- Inpatient pharmacy.
- Radiology with CPOE.
- Picture archiving and communication system (PACS).
- Human leukocyte antigen (HLA) and anatomic pathology.
- Management reporting.
- Transcription.
- Electronic prescription generation integrated with outpatient pharmacy.

CPOE for medications to be administered on site and documentation of care have been partially implemented. This type of integrated approach is a prerequisite for a fully electronic health record capable of enabling advanced clinical decision support, and taken together, these applications make up the system that serves as the electronic health record for the institution.

Context and Application

Our experience in attempting to achieve CPOE integrated with pharmacy, medication administration records, and clinical trial systems differs sharply from other published experiences of the use of CPOE for chemotherapy, including chemotherapy for pediatric patients. Kim, et al., used FMEA to guide implementation of CPOE for pediatric chemotherapy at a major academic medical center.[16] These authors demonstrated that errors for pediatric chemotherapy ordering, including dosing calculations and incomplete nursing checklists, were reduced after CPOE implementation for chemotherapy. However, the likelihood of incorrect doses on treatment plans did not change, and the likelihood of inappropriate matching of orders to treatment plans increased after CPOE, possibly because the system evaluated did not automatically link drugs and protocols. A reduction in chemotherapy-related errors after CPOE implementation was also reported by a Swiss hospital.[17]

There might be several reasons why our results were different from the experiences cited above. First, our CPOE implementation effort for pediatric chemotherapy was within the context of an integrated electronic health record, where preparation was being made for all aspects of the process to become electronic and fully integrated (e.g., nursing, pharmacy processes). This contrasts with other published efforts, which have focused on limited electronic ordering efforts. For example, the first study cited above modified a commercial pharmacy order-entry system (RxTFC®, BDM) for use as a CPOE application[16]; the second study appears to have been a rudimentary CPOE system, since a relational database product designed for personal computers was used (FileMaker Pro®).[17]

Beyond technical differences, the hospital setting and patient population might also have resulted in different chemotherapy CPOE implementation experiences. As a research hospital, where all patients are treated on protocols, chemotherapy regimens at our hospital often may be more

complex than those at other hospitals. In addition, specific chemotherapeutic agents might be dosed and administered differently in our research hospital, since pharmacokinetic studies are incorporated into most chemotherapy regimens. Moreover, we are comparing our CPOE system against a highly developed paper-based system that incorporated many of the features —e.g., limited formularies and preprinted order sets—that Kim, et al., first introduced electronically.[16]

Our experience illustrates the value for improving patient safety of formal process redesign specific to the exact technology and the environment in which it will be implemented. It is imperative to appreciate that new technologies to improve patient safety associated with medication use can also result in unintended consequences and error.[18] As a general principle, implementation of new electronic processes is associated with a "window of increased risk" as a consequence of errors of unfamiliarity by end users and undiscovered deficiencies of new processes (Figure 1). To achieve a future state of reduced error, it might be difficult to avoid this window of increased risk, but risks can be mitigated using the methods listed in Figure 1. We have found this figure useful to help our medical staff, administrators, and board members appreciate the rationale for increased vigilance in the initial implementation phase of technologies that are intrinsically believed to increase patient safety.

The gains we achieved by applying formal process redesign and work-system analysis to the implementation of chemotherapy orders should likewise be applicable to other new technologies, such as barcoding for point-of-care medication administration and "smart" infusion pumps.[19] Organizations accredited by the Joint Commission are required to complete one proactive risk assessment per year, and our data suggest that new technologies should be among an organization's top priorities for FMEA, particularly for high-risk and high-volume processes.[20]

Reengineering efforts not only answer "who," "what," and "when" questions associated with process changes, they also allow time for those affected by these changes to embrace the new technology by overcoming fears and anxieties associated with how change will affect them. Making changes without first allowing this period of adjustment and acceptance can lead to failure by revolt.[21, 22] In our experience, reengineering also provides a wealth of information for training staff. Training strategies and materials can be created to match process flows agreed upon at the end of the process-redesign sessions. Optimally, organizations that are investing substantial resources in CPOE and other new patient safety technologies should also

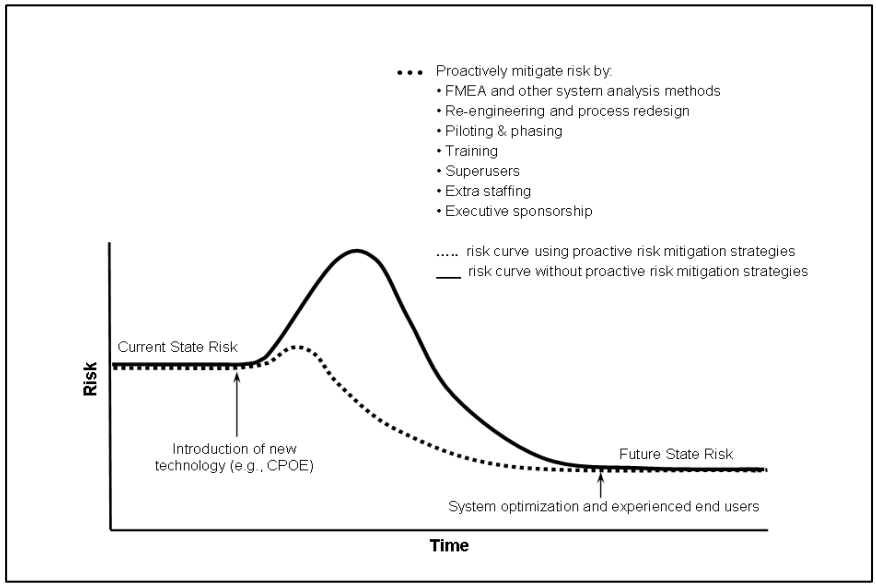

Figure 1. Implementation of new technologies often involves a window of increased risk before overall risk is reduced.

invest in dedicated reengineering staff who can consistently facilitate process redesign and workflow analysis in preparation for successful implementation.

Conclusion

Formal process redesign has proved crucial for safe and successful implementation of CPOE at our institution. We used this method to evaluate the use of CPOE to order chemotherapy for pediatric patients, and the analysis indicated that a commercial CPOE system was unable to exceed or even match the safety features of the current paper-based ordering process, pending further enhancements. Based on our experience, formal process redesign should be an essential element of the CPOE implementation process, particularly for areas of high-risk and high-volume care. Furthermore, these results suggest that process redesign should be employed for other technology implementations, such as barcoding and "smart" infusion pumps.

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