Computerized Physician Order Entry:

Costs, Benefits and Challenges

A Case Study Approach

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Executive Summary

Research indicates that computerized physician order entry (CPOE) has the potential to reduce medication errors and adverse drug events and thus improve the quality of care. However, successfully implementing CPOE is difficult and expensive. An estimated five percent of hospitals now have CPOE, but many more are considering this investment. This report is designed to expand the information base available to hospital leaders regarding CPOE implementation: the costs, challenges, benefits, and lessons learned.

Study Approach and Goals

Many of the early CPOE success stories involved custom-developed systems in large academic medical centers where residents, rather than community physicians, write most of the orders for patient care. The advent of vendor-based CPOE products has made CPOE more accessible to other types of hospitals, but less information has been available on these experiences. In particular, very limited data exists on the financial implications of CPOE – both costs and savings. As hospital leaders make decisions on where best to focus investments in patient safety, it is important to fill these gaps. To this end, this study examines the experiences of six health care delivery organizations that undertook CPOE implementation using vendor-based products – five that considered their implementations to be successful and one that halted the process midstream.

Costs

Based upon analysis of the data from the case study sites and a set of assumptions, the study presents a representative cost model for implementing CPOE at a single, 500-bed hospital. This model estimates total one-time capital plus operating costs of $7.9 million and annual ongoing costs of $1.35 million. The model assumes that the hospital organization already has the high-capacity network capabilities required for CPOE, and some level of clinical information system capability that would require moderate upgrades. Hospitals without such capabilities would incur higher costs. Variables important in determining the costs of CPOE include: the size of the organization, the number of sites, and whether the organization is implementing a single integrated clinical system or must integrate the new CPOE system with existing systems for laboratory, pharmacy and radiology.

Challenges

While the costs of implementation and ongoing maintenance represent one set of challenges, the managerial challenges can be even greater. The CPOE implementation team must alter physician practices and redesign inpatient care processes involving nurses, pharmacists, physicians and ancillary staff. Since CPOE often involves an increase in physician time spent on order entry, physician acceptance can be a critical barrier to overcome – especially in community hospitals where community physicians, rather than house staff, order the majority of tests and medications. The study sites invested heavily in executive and physician leadership. The time required to implement CPOE ranged from 12 to 24 months.

Benefits

The five hospitals studied made the decision to proceed with CPOE based on the benefits already documented by early adopters of the technology. These include: reduced adverse drug events, standardization of care, and improved efficiency of care delivery. With one exception, the study sites did not conduct, nor do they plan to conduct, comprehensive studies of the benefits and cost savings specific to their institution. The organization that did a formal study of the impact of CPOE found significant process improvements, elimination of medication transcription errors, and a small reduction in severity-adjusted length of stay at one hospital. However, they found no significant impact on overall costs. To date, the study organizations have documented some areas of modest cost savings, but are still early in the implementation process and the full financial implications (costs net of savings) are still unknown. It is important to note, however, that the organizations did not make the decision to implement CPOE based on an assumption that the system would pay for itself.

Lessons Learned

The study sites confirmed many of the success factors presented in earlier studies including: executive leadership commitment; the engagement of physician champions; continued dedication of financial resources beyond implementation; intensive user support; rapid computer response times; and user-friendly interfaces. The study sites also advocated practices that are less well-known, including: methods for quickly and efficiently gaining user input to design new care processes, to configure computer screens and to implement incremental improvements; the addition of wireless networks and devices for order entry; and heavy training of and reliance upon nursing staff to manage and assist with physician adoption of CPOE in the community setting.

Introduction

In recent years the value of computerized physician order entry (CPOE) systems for improving the quality of patient care has become more apparent. In particular, several studies have shown that CPOE systems are effective in reducing medication errors and adverse drug events (ADEs). [1,2] Employer groups,[3] government initiatives,[4] and others[5] are advocating hospital use of CPOE, and recent surveys have shown that many hospital leaders have taken steps to implement CPOE, or are preparing to do so in the near future.[6]

Still, CPOE is challenging and costly to implement and requires a high level of organizational commitment to achieve its potential benefits. The relatively low rate of adoption of CPOE across the country (we estimate less than 5% of U.S. hospitals[7]) reflects these challenges. In addition, the best publicized early CPOE success stories involve custom-developed systems (as opposed to purchased vendor products), installed in academic medical centers (where residents write many of the orders). To expand the knowledge base on CPOE, all the sites selected for this study installed vendor-based CPOE systems, including one community hospital.

To date there have been few efforts to specifically identify and quantify the costs and benefits of implementing CPOE across different kinds of hospitals with varying vendor software systems. This study examines the relative costs of CPOE at individual institutions, and places these findings in the context of existing literature of the field. We conducted case studies of six organizations that have implemented, or attempted to implement, CPOE systems in recent years. All organizations have utilized vendor-supplied systems, as opposed to systems developed in-house. The five that have been successful have implemented systems across multiple clinical environments, and have physicians placing the majority of orders electronically. We have examined the full range of costs incurred for each organization's CPOE initiative, from planning through implementation to ongoing support, and the range of benefits that they have measured and are planning to measure. From this analysis we have constructed a model that may be used to approximate the costs of a CPOE implementation, taking into consideration a number of organizational variables.

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[1] Bates DW, Leape LL, Cullen DJ, et al. Effect of Computerized Physician Order Entry and a Team Intervention on Prevention of Serious Medication Errors. JAMA 1998;280:1311-1316.
[2] Evans RS, Pestotnik SL, Classen DC, et al. A Computer-Assisted Management Program for Antibiotics and Other Antiinfective Agents. NEJM 1998;338:232-8.
[3] The Leapfrog Group, www.leapfroggroup.org.
[4] SB 1875 (Speier, Chapter 816) Health Facilities and Clinics: Medication-Related Errors. [Introduced in the California Senate; 24 February 2000.]; and United States. Cong. Senate. 107th Congress, 2nd Session. S. 2638, Efficiency in Health Care (eHealth) Act of 2002. [Introduced in the US Senate; 18 June 2002].
[5] Institute for Safe Medication Practices, "A Call to Action: Eliminate Handwritten Prescriptions Within 3 Years," 2000.
[6] According to a November 2002 Deloitte & Touche report, "The Future of Health Care," health care CEOs cite CPOE as the clinical system most likely to be implemented or upgraded over the next two years (61%).
[7] According to the definition of use: greater than 50% of orders placed by physicians electronically.

Background

The organizations that participated in our case studies all indicated that they were aware of the literature from leaders in the field of CPOE and believed that the case for pursuing CPOE implementation had been made. In setting the context for this study, therefore, it is important to review the literature and the reasons for the heightened level of interest in CPOE.

What Is CPOE?

Order writing is the mechanism through which physicians' diagnostic and therapeutic plans are converted into action. Virtually every intervention in patient care outside of surgery – performing diagnostic tests, administering medications, taking a patient's vital signs – is initiated by a physician's written order. This critical step in the care process represents a point where intervention can have a high impact on preventing medication errors and improving adherence to care guidelines.

At the most basic level, CPOE is a computer application that accepts physician orders electronically, replacing hand-written orders on an order sheet or prescription pad. The computer can then offer the physician decision support at the point of ordering. For example, an order for a drug to which the patient is allergic would trigger an immediate alert by the computer, warning of the allergy and possibly recommending an alternative medication. An order for a new laboratory test might trigger an alert telling the physician that the test had recently been ordered and that a result was pending. An order for a particularly expensive test or medication might trigger display of the cost and offer alternatives or a list of restricted indications.

If the physician is ordering a series of tests and medications for a common diagnosis, the computer can offer the use of a pre-programmed, institutionally reviewed and approved set of orders to facilitate the process and help the physician follow accepted protocols for that diagnosis. In addition, complex order types involving calculations and multiple-day orders dependent on test results (such as protocols for anticoagulation, cancer chemotherapy, and HIV therapy) can be programmed into the system. An extensive discussion of the different kinds of clinical decision support offered by CPOE can be found elsewhere.[8]

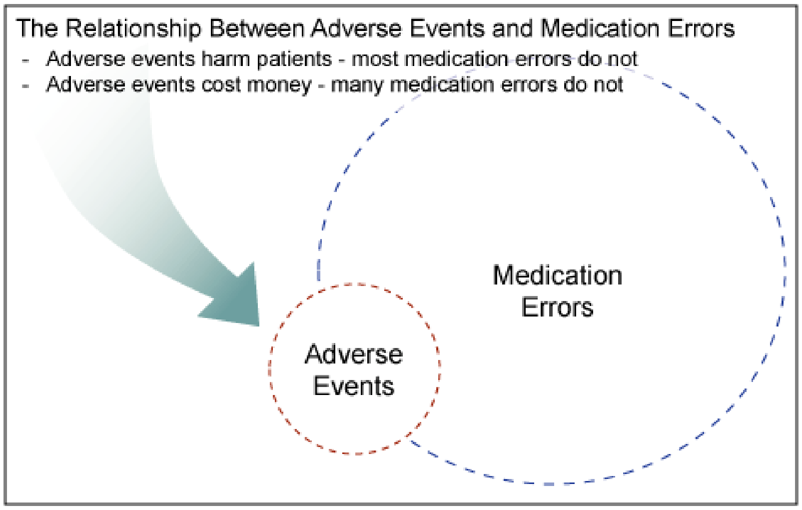
In most (but not all) CPOE implementations, orders entered into the system are communicated electronically to the departments and personnel responsible for their execution, and frequently, the departments send back notification of the status of the order and/or the results of order execution (e.g., laboratory results, x-ray results). CPOE can thus improve process turnaround times – for example, reduce the time from ordering to arrival of the medication. It can improve documentation received by ancillary departments, such as pharmacy and radiology, thereby reducing the chance of misinterpretation of an order and improving documentation needed for payment. CPOE can also reduce the time required for ancillary department personnel to complete the order by reducing the need for re-entry of data into the ancillary computer system. These are the sources of some of the potential efficiencies afforded by CPOE.

[8] Metzger J and Turisco F. Computerized Physician Order Entry: A Look at the Marketplace and Getting Started. The Leapfrog Group (www.leapfroggroup.org) and First Consulting Group, 2001.

Benefits from CPOE

The principle goals of CPOE are improved medication safety (reducing adverse drug events, or ADEs), reducing unnecessary variation in care, and improving the efficiency of care delivery. Of the three, improving medication safety is by far the most frequently cited justification.

Adverse drug events: incidence. It is important at the outset to define two terms and clarify the relationship between them. A *medication error* is an error in the process of ordering, dispensing or administering a medication, regardless of whether an injury occurred or whether the potential for injury was present.[9] An *adverse drug event* is an injury resulting from the use of a drug, which may or may not result from an error.[10] Thus, a medication error may lead to an ADE, but does not necessarily do so. Indeed the vast majority of medication errors do not result in any harm to the patient.



Similarly, not all ADEs are caused by medication errors; those that are have been termed *preventable* ADEs. However, the exact proportion of ADEs that are preventable is not known. The goal of medication safety interventions (including CPOE) is to prevent or intercept medication errors that could lead to ADEs.

Much of the current interest in ADEs dates to the release of the Institute of Medicine's 1999 report, *To Err Is Human*.[11] This report cited evidence from multiple studies to indicate that medical errors are responsible for 50,000 -100,000 deaths annually in the United States, with ADEs accounting for a sizeable proportion of those deaths. The report, however, drew from earlier studies of the frequency and severity of ADEs dating back over a decade. Much of the data were derived from two large-scale studies.

The first of these, the Harvard Medical Practice Study, examined 30,000 inpatient admissions in New York State in 1984 using retrospective chart review. Investigators conducted a similar study of 15,000 admissions to hospitals in Utah and Colorado in 1992. The results of the two studies were similar: ADEs constituted 19% of all adverse

[9] Bates DW, Teich JM, Lee J, et al. The Impact of Computerized Physician Order Entry on Medication Error Prevention. JAMA 1999;6(4):313-321.
[10] Cullen DJ, Bates DW, Small SD, et al. The Incident Reporting System Does Not Detect Adverse Drug Events. Joint Commission Journal on Quality Improvement 1995;21(10):541-548.
[11] Institute of Medicine, Committee on Quality of Health Care in America. To Err Is Human: Building a Safer Health System, Washington, D.C., National Academy Press; 1999.

events, the largest single category after surgical events. Overall, between 2.9% and 3.7% of admissions were complicated by ADEs.

Quantifying ADEs is very difficult. Most hospitals have implemented voluntary reporting systems where caregivers report adverse events that they witness or are involved in (although these mechanisms are thought to under-report the actual rate of ADEs since care givers can be hesitant to report errors or often do not recognize their occurrence). However, new approaches to measuring the incidence of ADEs have made possible more sensitive detection of events at the time they occur. Computerized surveillance approaches have been developed for screening electronic clinical data (pharmacy orders, laboratory orders and results) for evidence of a possible ADE.[12] For example, an order for naloxone – an antidote for a narcotics overdose – suggests the occurrence of a narcotics-related ADE; a greatly elevated theophylline blood level suggests an ADE due to that drug. Using such a system, in conjunction with a process for investigating and validating each incident, investigators at LDS Hospital verified the occurrence of 999 ADEs in a two year period, compared with six ADEs reported annually through the voluntary system.[13]

More recent data using such surveillance techniques indicate that the incidence of ADEs is substantially higher than the earlier Harvard Medical Practice Study suggests. A study conducted at the Brigham and Women's Hospital in Boston using automated surveillance detected significant ADEs in 10% of admissions.[14] Manual chart reviews completed by hospitals participating in an Institute for Healthcare Improvement initiative suggest that there may be an even higher incidence than that detected in the Brigham and Women's study.[12]

Adverse drug events: costs. Two studies published in 1997[15,16] addressed for the first time the financial implications of ADEs in hospitalized patients. Using somewhat different methodologies, the two studies arrived at similar figures, estimating the attributable cost of a single ADE at $2,013-$2,595. These costs were related to increased length of stay and did not include other potential costs such as losses through litigation or loss of market share due to publicity surrounding adverse events. Given an ADE incidence of 10% of admissions (as mentioned in the Brigham and Women's Hospital study), this implies that a hospital with 25,000 admissions annually incurs over $5 million in additional costs attributable to ADEs. This does not include the costs of claims losses resulting from ADE-related medical negligence lawsuits. Such losses cost one self-insured academic organization over $70 million between the years 1990-1999.[17] Another

[12] Kilbridge P and Classen D. Surveillance for Adverse Drug Events: History, Methods and Current Issues. VHA Research Series 2002, Volume 3, VHA Inc.
[13] Classen DC, Pestotnik SL, Evans RS, Burke JP. Description of a computerized adverse drug event monitor using a hospital information system. Hospital Pharmacy. 1992 September;27(9):774, 776-9, 783.
[14] Jha AK, Kuperman GJ, Teich JM, et al. Identifying Adverse Drug Events. JAMA 1998;5(3):305-314.
[15]Classen DC, Pestotnik SL, Evans RS, et al. Adverse Drug Events in Hospitalized Patients: Excess Length of stay, extra costs, and attributable mortality. JAMA 1997;277:301-306.
[16] Bates DW, Spell N, Cullen DJ, et al. The Costs of Adverse Events in Hospitalized Patients. JAMA 1997;277:307-311.
[17] Risk Management Foundation of the Harvard Medical Institutions, Forum, May 2000, Volume 20 Number 3.

study showed the average claim paid for an ADE-related event to be $376,000.[18] While it is not certain how many of these ADEs can be prevented by CPOE or other means, these represent large costs to the health care system.

ADE prevention. CPOE can play an important role in improving medication safety. While ADEs can originate with errors made at any point during the medication administration process – from history taking through physician ordering to pharmacy evaluation, dispensing, and administration to the patient[19, 20] – one study showed that the largest single proportion of ADEs (approximately 50%) originate with errors during medication ordering.[20] Computerized ordering can offer the opportunity to provide vital information to physicians at the point of ordering, such as warning of drug interactions or patient allergies to a medication, and screening for proper dosing according to a patient's age, weight, or renal function.

The table on the following page illustrates where adverse drug events originate in the medication management process.

Two studies in particular illustrated the potential of CPOE to reduce medication errors and improve patient safety. A study performed at Brigham and Women's Hospital demonstrated a 55% reduction in serious medication errors and a 17% reduction in ADEs (although the latter reduction was not statistically significant).[1] Investigators at LDS Hospital, using a CPOE system for ordering anti-infective agents in the ICU, were able to demonstrate a 70% reduction in ADEs due to antibiotics through the use of the system.[2]

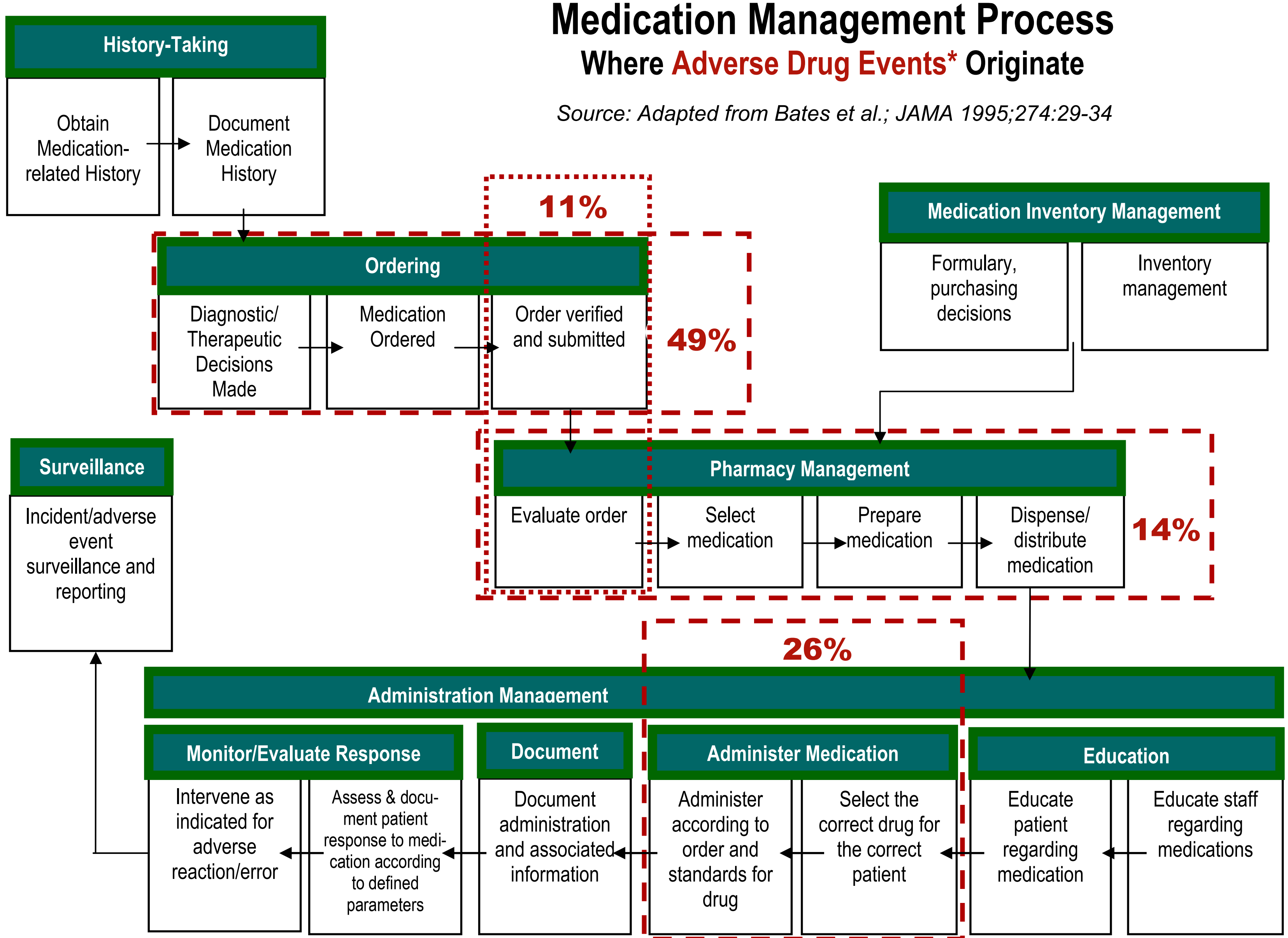
It is worth emphasizing that while CPOE is the focus of much attention, it is by no means the only intervention that may reduce ADEs. Stand-alone pharmacy information systems can reduce the number of medication errors by alerting pharmacists to drug, allergy, and laboratory interactions. An electronic medication administration system can streamline the documentation and tracking of medication profiles and administration, although this technology is most effective when used in conjunction with CPOE. Medication administration systems that utilize bar code systems to identify medications, patients, and the administering clinician have also been shown to reduce administration errors in some studies.[21] This is particularly significant because unlike order entry errors, mistakes made during medication administration always reach the patient (e.g., are not intercepted by other caregivers prior to medication administration). Further, there are other process interventions that have been advocated for use to improve medication

[18] Rothschild JM, et al. Analysis of Medication-Related Malpractice Claims: Causes, Preventability, and Costs. Archives of Internal Medicine 2002;162:2414-2420.
[19] Kilbridge P and Classen D. A Process Model of Inpatient Medication Management and Information Technology Interventions to Improve Patient Safety. VHA Research Series2001, Volume 1, VHA Inc.
[20] Bates DW, et al. Incidence of Adverse Drug Events and Potential Adverse Drug Events. JAMA 1995;274:29-34.
[21] Patterson, E. Improving Patient Safety by Identifying Side Effects from Introducing Bar Coding in Medication Administration. JAMIA 2002; 9:540-53.

Medication Management Process

Where Adverse Drug Events* Originate

Source: Adapted from Bates et al.; JAMA 1995;274:29-34



*Dotted boxes represent the percentage of errors occurring at specific points in the medication management process.

safety and the ordering process,[22] including care pathways that detail essential steps for patient care.[23]

In addition, it should be noted that technologies designed to reduce medication errors can occasionally introduce new errors.[24,25] For example, a set of orders for potassium chloride supplements that doesn't specify the rate of administering this medication could lead to serious adverse events.[9] This risk increases the importance of maintaining other traditional safety processes such as adverse event surveillance and procedures for investigating medication errors.

Standardization of care. CPOE can offer multiple mechanisms for presenting treatment- or diagnosis-specific decision support to physicians at the point of ordering, including standardized order sets for diagnoses or therapies, current practice guidelines for the optimal use of medications, and recommendations for additional or adjunct orders to consider in specific situations. Such decision support helps to reduce unnecessary variations in care by steering physicians toward recognized best practices.

Studies from at least four organizations support the ability of CPOE to improve adherence to organizational care guidelines with the use of CPOE. For example, use of CPOE-linked computerized guidelines for ordering of H-2 blockers, intravenous antiemetics, and subcutaneous heparin at the Brigham and Women's Hospital resulted in rapid and widespread adoption of recommended prescribing practices for these medications.[26] In the four weeks before CPOE was implemented, 16% of orders for H-2 blockers complied with formulary best practice. Four weeks after introducing CPOE, 95% of such orders were in compliance and 97% were in compliance two years later. When a new medication was added to the formulary as a preferred drug, its use went from 0% to 71% in one week, and 97% in four weeks. In a study at the Regenstrief Institute, computerized recommendations for "corollary" orders – orders for additional medications or tests that should accompany a particular medication order, such as an order to measure a drug level when prescribing certain toxic antibiotics – resulted in a reduction in errors of omission and improved adherence to institutional prescribing guidelines.[27] Kaiser Permanente Northwest demonstrated dramatic improvements in adherence to guidelines for upper GI testing and chest radiography, and antidepressant selection via CPOE.[28] Queens Medical Center in Hawaii demonstrated improved adherence to recommendations for monitoring of acute myocardial infarction and H2

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[22] Leape LL, Kabcenell A, Berwick D, Roessner J. IHI Breakthrough Series: Reducing Adverse Drug Events. Institute for Healthcare Improvement, 1998.

[23] Renholm M, Leino-Kilpi H., Suominen T. Critical Pathways: A Systematic Review. JONA April 2002; 32(4):196-202.

[24] Massaro TA. Introducing Physician Order Entry at a Major Academic Medical Center: I. Impact on Organizational Culture and Behavior. Academic Medicine January 1993; Vol. 68(1): 25-30.

[25] Bates DW et al. The Impact of Computerized Physician Order Entry on Medical Error Prevention. JAMIA 1999; 6:313-21.

[26] Teich JM et al., Effects of Computerized Physician Order Entry on Prescribing Practices, Archives of Internal Medicine 2000;160:2741-2747.

[27] Overhage JM, Tierney WM, Zhou XH, et al. A Randomized Trial of "Corollary Orders" to Prevent Errors of Omission, JAMIA 1997;4:364-375.

[28] Chin HL and Wallace P. Embedding Guidelines Into Direct Physician Order Entry. Proceedings of the 1999 AMIA Annual Symposium, p. 221-225.

blockers, as well as reductions in inappropriate use of restricted antibiotics and non-formulary drugs.[29]

Improved efficiency of care delivery. By automating a manual task, CPOE offers the opportunity to move information instantly around the organization, reducing turnaround times for medication delivery, obtaining and processing laboratory specimens, scheduling and completing radiology examinations, and other tasks. Process efficiencies provide value not only through the potential for cost savings, but by improving quality of care (better information available earlier; earlier therapeutic interventions); freeing up valuable resources such as pharmacists, nurses and other staff from administrative tasks, enabling them to provide higher value clinical services; and improving regulatory compliance (e.g., better documentation and co-signature compliance). As will be discussed later, published experience has shown that in the most successful implementations, CPOE does not require more time overall from physicians; often, however, *more* time is spent completing orders using CPOE.[30]

A number of organizations have demonstrated reduced medication turnaround times. Queens Medical Center showed a 40% reduction in cycle time for ordering STAT medications;[29] Montefiore Medical Center in New York demonstrated a 58% reduction in medication turn-around times after CPOE implementation, and estimated time savings of two hours per day for each ward clerk, 20 minutes per day per nurse, and 200 minutes per day per pharmacist.[31] In organizations where orders from CPOE are electronically communicated to the pharmacy information system, pharmacists report timesavings from eliminating redundant order entry, as well as from improved decision support. Pharmacists also spend less time calling physicians to clarify or modify orders. This frees pharmacists to participate more actively in direct patient care activities.[32] Other efficiencies cited with CPOE include reductions in unsigned orders[29,36] and reduced duplicate and redundant test ordering.[33]

See the following table for a summary of the relevant literature on CPOE benefits.

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[29] Davis DC et al., Chapter 2 of the Fifth Annual Proceedings of the CPR Recognition Symposium, 1999.

[30] Tierney WM, Miller ME, Overhage JM, et al. Physician Inpatient Order Writing on Microcomputer Workstations: Effects on Resource Utilization. JAMA 1993;269:379-383.

[31] Manzo J, Taylor RG, and Cusick D, Measuring Medication-Related ROI and Process Improvement after Implementing CPOE. Presentation of findings from Montefiore Medical Center, Bronx, New York, 2000.

[32] Personal communications: Maimonides Medical Center, Brigham and Women's Hospital.

[33] Bates DW, Kuperman GJ, Rittenberg E, et al. A Randomized Trial of a Computer-based Intervention to Reduce Utilization of Redundant Laboratory Tests. American Journal of Medicine 1999;106:144-150.

Categories of CPOE Benefits from the Literature

	Benefits	Examples
Adverse Drug Event Reduction	Reduced ADEs through decision support for medication ordering (interaction checking, etc.)	• 55% reduction in serious medication errors[1] • 70% reduction in adverse drug events[2]
Standardization of Care	Better adherence to standards of care yields better therapy, and ultimately, better outcomes at lower costs	• Increased use of preferred H2 blocker from 15.6% to 81.3%; decrease in doses exceeding maximum recommended from 2.1% to 0.6%; increase in use of heparin in patients at bed rest from 24% to 47%[3] • Increase in ordering of recommended "corollary" orders from 21.9% to 46.3% with CPOE reminder[4] • Improved guideline adherence for upper GI orders from 55% to 86-90%; decrease in total number of UGI orders from 10.6 per 1000 patients to 5.6 per 1000; 20% reduction in chest x-ray orders, with CPOE guidelines[5] • 75% reduction in inappropriate vancomycin use; 80% increase in Troponin orders for MI; 60% decrease in CK orders for MI[6]
Improved Efficiency of Care Delivery	More prompt diagnosis and therapeutic intervention; better use of scarce resources; better regulatory compliance	• 60% decrease in time to first dose of medication; 40% reduction in time for STAT medications[6] • 85% reduction in unsigned orders[6] • Panic lab response time reduced from 2.1 to 0.7 hours[7]
Cost Savings	Reduced length of stay; reduced utilization of tests and expensive medications	• $1 million in laboratory charges (representing a 5% reduction in ordering) through display of costs of test[7] • $500,000 reduction in pharmacy charges through dosage recommendation change for a single drug (representing 92% switch to new dose)[7] • $500,000 in laboratory charges (representing a 10% decrease in labs ordered) through restriction of advance ordering of laboratory studies from 7 to 3 days[7] • $500,000-$1 million in reduced charges with IV-to-PO medication route switch rule (representing a 25% result in change to oral delivery)[7] • Reduction in drug costs (from mean $340 per patient to $102), length of stay (from 12.9 to 10.0 days), and overall hospital costs (from $35,283 to $26,315) through CPOE for antibiotic ordering[2] • 13% reduction in charges for diagnostic tests[8] • 12.7% reduction in total inpatient charges ($887 per patient) with CPOE use[9]

[1]Bates DW, Leape LL, Cullen DJ, et al. Effect of Computerized Physician Order Entry and a Team Intervention on Prevention of Serious Medication Errors. JAMA 1998;280:1311-1316.
[2]Evans RS, Pestotnik SL, Classen DC, et al. A Computer-Assisted Management Program for Antibiotics and Other Antiinfective Agents. NEJM 1998;338:232-8.
[3]Teich J et al., Effects of Computerized Physician Order Entry on Prescribing Practices, Archives of Internal Medicine 2000;160:2741-2747.
[4]Overhage JM, Tierney WM, Zhou XH, et al. A Randomized Trial of "Corollary Orders" to Prevent Errors of Omission, JAMIA 1997;4:364-375.
[5]Chin HL and Wallace P. Embedding Guidelines Into Direct Physician Order Entry. Proceedings of the 1999 AMIA Annual Symposium, p. 221-225.
[6]Davis DC et al., Chapter 2 of the Fifth Annual Proceedings of the CPR Recognition Symposium, 1999.
[7]Teich J et al., Chapter 1 of the Second Annual Proceedings of the CPR Recognition Symposium, 1996.
[8]Tierney WM, Miller ME, and McDonald CJ. The Effect on Test Ordering of Informing Physicians of the Charges for Outpatient Diagnostic Tests. NEJM 1990;322:1499-1504.
[9]Tierney WM, Miller ME, Overhage JM, et al. Physician Inpatient Order Writing on Microcomputer Workstations: Effects on Resource Utilization. JAMA 1993;269:379-383.

Note: While the benefits cited in this table include a sample of those most representative of what is believed to be achievable by hospital organizations, the results are specific for those organizations and the patient populations studied.

Cost savings. Given the high costs of ADEs (discussed previously) and the effect of ADEs on length of stay, a reduction in the incidence of ADEs can reduce the costs of patient care. Sometimes these savings help *hospitals* financially – like a reduction in length of stay for a Medicare case where payment is fixed. But sometimes these savings accrue to the *payer* – e.g., when the payment is based on hospital charges or a fixed amount per day of care. Although benefits accrue to both payers and providers, to date, the cost of CPOE has been assumed by hospitals. However, a few employers and payers are beginning to consider contributing to the cost of CPOE systems.[34]

While cost savings are closely related to improvements in care process efficiencies, such improvements may or may not translate to reduced costs. Two studies have demonstrated real cost savings when such efficiencies translate to reduced length of stay or reduced utilization of tests and expensive medications. For example, the LDS study of CPOE use in the ICU demonstrated more than threefold reductions in the cost of antibiotics, more than a three-day decrease in the length of hospital stay, and a more than 25% reduction in total hospital costs for patients where CPOE decision support was used, compared to a similar patient group before CPOE was implemented.[2] The Regenstrief Institute published similar findings, showing a 12.7% reduction in total inpatient charges per admission with CPOE use on an internal medicine ward due to reductions in bed, diagnostic, and medication charges, and length of stay.[30] Reminding physicians of the charges associated with diagnostic tests and alerting them when a potential duplicate laboratory test is ordered results in significant reductions in unnecessary testing and subsequent savings.[35,36]

In addition to potential for savings, improved documentation and coding with CPOE use can result in increased revenue capture in departments such as radiology, which are heavily dependent on documentation to obtain payment.

Experience to Date with CPOE: Successes and Failures

The concept of employing direct computerized order entry by physicians to improve the quality of care dates to the 1970s.[37] One hospital information vendor, Technicon Data Systems (later known as TDS), designed a system specifically around physician order entry, and a number of pioneer organizations implemented CPOE using this system in the 1970s and 1980s. Successful implementations of the TDS system demonstrated the potential for medication safety improvement using CPOE.[38]

Subsequent to the first vendor-developed system, three academic medical centers that constructed their own hospital information systems provided the foundation for much current thinking about CPOE, demonstrating the potential of such systems to improve care, as well as critical success factors for achieving implementation and widespread

[34] Payer Gives Bonus for CPOE. Health Data Management Online, July 8, 2002.
[35] Tierney WM, Miller ME, and McDonald CJ. The Effect on Test Ordering of Informing Physicians of the Charges for Outpatient Diagnostic Tests. NEJM 1990;3221499-1504.
[36] Teich JM et al., Chapter 1 of the Second Annual Proceedings of the CPR Recognition Symposium, 1996.
[37] Sittig and Stead, Computer-based Physician Order Entry: The State of the Art. JAMIA 1994;1:108-23.
[38] Barrett JP, Barnum RA, Gordon BB, et al. Final Report on Evaluation of the Implementation of a Medical Information System in a General Community Hospital. Battelle Laboratories (NTIS PB 248 340), Dec. 19, 1975.

physician acceptance. Many of the benefits discussed previously were described by these institutions. The Regenstrief Medical Record System, built by investigators at Wishard Memorial Hospital in Indianapolis, implemented computerized physician ordering beginning in the early 1980s. The Regenstrief system was one of the earliest to employ patient-specific clinical data to provide decision support at the time of ordering. The Brigham and Women's Hospital in Boston developed and implemented CPOE beginning in the early 1990s, and demonstrated a wide variety of quality and cost savings from use of the system.[36] The LDS Hospital in Salt Lake City implemented aspects of computerized ordering for blood products,[39] and later for total parenteral nutrition, ventilator management, and antibiotics. [2,40,41]

Challenges of CPOE

Cumbersome interfaces and time-consuming ordering processes, along with lack of clinical process redesign at the time of implementation, resulted in several early CPOE failures. The University of Virginia's experience in the late 1980s offers one of the best descriptions of some of the difficulties of CPOE.[42,43] In spite of apparent support by administrative and clinical leadership, the implementation was problematic for several reasons. Most important, the leadership underestimated the impact of CPOE on clinical workflow as well as physician and nursing tasks, and did not invest sufficient resources in the effort. Primary physician users – residents – perceived the effort as an information systems department, rather than a clinician-lead, initiative that was being forced upon them in an inflexible manner.

The ultimate goals of CPOE were understood by senior leadership, but these objectives were not communicated to, or perceived by, the average staff or resident physician. As a result, they felt that administration was trying to turn them into clerks to save money. Finally, residents felt that the system was cumbersome and too time consuming to use. A rebellion and work action by the house staff eventually precipitated a systemic review of the effort. The issues were resolved eventually by the establishment of an executive project team representing clinical departments, nursing, and information services.

The experience points out some of the obstacles encountered when implementing CPOE. Any organization attempting the effort faces four principle categories of challenges: affording the initial investment and ongoing costs; changing the way physicians work; redesigning inpatient care processes that affect physicians, pharmacists, nurses, and ancillary personnel; and implementing a highly reliable, responsive, and user-friendly CPOE system.

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[39] Lepage EF, Gardner RM, Laub MR, et al. Improving Blood Transfusion Practice: Role of a Computerized Hospital Information System. Transfusion 1992;32:253-9.
[40] Pestotnik SL et al., Implementing Antibiotic Practice Guidelines through Computer-Assisted Decision Support: Clinical and Financial Outcomes. Annals of Internal Medicine May 151996;124:884-890.
[41] Haug PJ, Gardner RM, Tate KE, Evans RS, East TD, Kuperman G, Pryor TA, Huff SM, Warner HR. Decision Support in Medicine: Examples from the HELP System. Computers and Biomedical Research 1994; 27(2)396-418.
[42] Massaro TA. Introducing Physician Order Entry at a Major Academic Medical Center: I. Impact on Organizational Culture and Behavior. Academic Medicine 1993;68:20-25.
[43] Massaro TA. Introducing Physician Order Entry at a Major Academic Medical Center: II. Impact on Medical Education. Academic Medicine 1993;68:25-30.

Changing physician practice. Literature and experience show that computerized order entry does not save physicians time during the ordering process, although efficiencies are realized elsewhere (e.g., fewer calls from pharmacists, nursing, ancillaries to clarify orders). The most successful CPOE implementations are essentially time-neutral compared with handwriting orders, and an increase in time required to write orders is common.[29]

Switching from hand writing to computer ordering requires a significant change in physician work patterns. They must work at a workstation, or with a wireless computer, and some keyboard data entry is required. To achieve the benefits of CPOE and clinical decision support, at least one study site chose to keep verbal orders to a minimum, to be used only in emergencies and with after-the-fact electronic signature by the physician. Sometimes physicians must respond to requests for additional information presented by the system during the ordering process and this prolongs the process (albeit while improving the appropriateness and safety of the resulting orders). Given physicians' hectic workdays, asking them to spend additional time on a task that was previously performed more quickly and easily by hand is not a trivial request. Providing a fast, highly responsive ordering interface is necessary – but not sufficient – to winning physician acceptance. [44,37]

Rather, literature and experience have shown that to succeed in altering physician practice, the organization's leadership – clinical and administrative – has to clearly and continuously articulate and communicate to physicians what they and their patients will gain from the use of CPOE. This task is greatly facilitated by the active involvement of one or more physician champions – "true believers" who work with their colleagues to assist them in adapting to the new system and serve as liaisons to the information systems group. These physician champions must be well-recognized clinicians in their own right in order to have the credibility necessary to be effective in this role.[36,44,45]

Redesigning inpatient care processes. CPOE is not simply a niche computer system used by physicians in place of handwritten orders. Rather, it is the capstone of an entire process – that of order management. As such, it directly impacts not only physician ordering but also physician decision making (through the decision support features), care planning, pharmacist decision making and workflow, nursing workflow and documentation, and communication with ancillary services (laboratory, radiology, etc.).[37] Implementing CPOE profoundly alters the way all of these participants do their jobs. The participants in the current study affirm that achieving this level of organizational change requires consistent support from leadership, plus dedicated resources and commitment from all affected constituencies.[46]

Successful transition to a CPOE environment requires that current workflows be carefully analyzed and post-implementation workflow changes anticipated and designed. Specific policies and procedures have to be developed for managing the transition from manual to computerized ordering. For example, appropriate indications and procedures

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[44] Bates DW, Kuperman G, and Teich JM. Computerized physician order entry and the quality of care. Quality Management in Health Care, 1994;2:18-27.
[45] Drazen E and Metzger J, Strategies for Integrated Health Care, Chapter 9. 1999, Josey-Bass, San Francisco.
[46] Ahmad A, Teater P, Bentley TD, et al. Key Attributes of a Successful Physician Order Entry System Implementation in a Multi-Hospital Environment. JAMIA 2002;9:16-24.

for managing verbal orders must be decided in advance of system implementation. Procedures must be established for managing patient records and orders as patients move between CPOE and non-CPOE environments, as will happen during implementation if not afterward. The manner in which nurses are to be made aware of new orders in the system has to be decided: Are nurses expected to survey their patients' online records several times per shift? Will they be notified electronically of new orders in some way? Or will all new orders print out on the care unit? These are only a few examples of the many decisions about critical details of patient care that must be made in advance of implementation.

In addition, decisions must be made about how to manage compliance with new work processes. For example, whether to mandate electronic ordering or make it optional or whether to support development of "personalized" (physician-specific) order sets.

Implementing a reliable computer system for CPOE. Finally, in addition to addressing the cultural and organizational challenges, the CPOE system implemented must function well, providing both a satisfactory user experience and sufficient clinical decision support to address the quality objectives of CPOE. The system must be sufficiently user-friendly to accommodate both experienced and novice computer users. Most important, the system has to be fast, with a minimal number of computer screens required for viewing and entering, and the shortest possible response times during all kinds of routine ordering.[44] Decision support rules must be highly customizable, permitting the construction of order sets, conditional guidelines and protocols, and rules or other kinds of logic needed to intercept dangerous medication orders.

The most valuable decision support for preventing ADEs is that which takes into account both patient- and order-specific data when constructing advice.[15,47] For example, an order for digoxin in a patient with a low serum potassium should trigger a warning and perhaps a suggestion to order potassium supplements; an order for an adult dose of a medication in a small pediatric patient should be met with a warning, and ideally, a weight-appropriate dose recommendation. Providing this kind of advice requires the CPOE decision support module to receive and process data from multiple computer systems (in these examples, laboratory and clinical documentation systems). This requirement means that multiple software interfaces between ancillary systems and the CPOE system must be built, or one unified set of applications must be installed.

A number of satisfactory vendor software products for CPOE are on the market today and experience with their use is gradually accumulating. These products range from independent components that can be implemented in a multi-vendor hospital information system environment to comprehensive, integrated hospital-wide systems (systems representing both extremes and the spectrum between have been successfully implemented). The availability of satisfactory vendor products should make CPOE more accessible to organizations that did not have the experience or resources to develop a "homegrown" system like many of the early adopters.[8]

The costs of CPOE. Without question CPOE is expensive, but just how expensive depends upon a multitude of organization-specific variables. The cost of CPOE software

[47] Evans, Pestotnik, Classen, et al. Prevention of Adverse Drug Events Through Computerized Surveillance. Proc. Annual Symposium on Computer Applications in Medical Care 1992, p.437-41.

products varies enormously – not only among vendors but even as sold by a single vendor, depending on individual pricing arrangements. Even greater are the costs of implementation and ongoing maintenance and support.

Our study sites believe that the potential of CPOE to improve patient safety and care delivery has been demonstrated and while the goal of implementing these systems at the study sites was not financial gain, the cost impact upon the organization cannot be ignored. Policies to encourage the adoption of CPOE by hospitals should take these costs into consideration. In view of these realities, it is important to develop a better understanding of the actual financial costs and benefits of purchasing, implementing, and supporting CPOE systems.

This study presents an approach to analyzing the costs of CPOE that takes into account a variety of parameters identified in the case studies that influence the scale and scope of implementation and thereby determine cost. We used this approach to assess the costs of CPOE purchase, implementation, and maintenance at five organizations that have successfully implemented CPOE using commercially available software.

The following section highlights our findings on the costs of CPOE.

A Cost Assessment for CPOE Implementations

Potential Determinants of Overall Cost

There exists little published information on the costs of implementing CPOE. Studies to date have been based principally on generic estimates or total costs cited by a handful of organizations.[48] However it should be possible to make useful observations and predictions about costs by taking into consideration certain categories of technological and environmental variables faced by organizations. We developed an approach to studying organizations that takes into account multiple parameters that determine the scope of the effort and thereby overall cost. These variables include the following:

Organizational size and complexity: the number and size of sites implementing CPOE. A small- or medium-sized single hospital implementing inpatient CPOE would represent the simplest case. By contrast, a multi-hospital system faces challenges that increase with the number of sites: different clinical cultures, local leadership and information technology platforms, plus the need to communicate and access information across sites when warranted by the organization. A health care organization that chooses to implement a CPOE system across both inpatient and outpatient environments represents an additional level of complexity.

Existing technology baseline prior to the CPOE initiative: technology infrastructure and clinical information systems currently in place. Most CPOE implementations of vendor products include order communications systems that send orders from the CPOE module to ancillary departments and other hospital systems (e.g., lab, radiology, ADT, etc.) and receive information back from these systems. With the implementation of order communication, the volume of network transactions can increase dramatically. An organization that is implementing order communications for the first time therefore needs to have in place a modern **network infrastructure** – the cables, switches, and other technology that carry and manage the flow of data throughout the enterprise – that is capable of handling this level of traffic. Specifically, hospitals need to have in place a local area network (LAN) that uses Category 5 cable at a minimum and a redundant design with an adequate level of standby and backup devices to stay operational at all times – in industry parlance:"5 9's" up-time (the network must be up and operating 99.999% of the time). In addition, network management capabilities are required to support load balancing and network monitoring (providing alerts for outages, potential intrusions and performance problems).

At the time of this writing, many hospitals have upgraded to a level of network connectivity sufficient to manage these transaction volumes;[49] those who have not would face a significant investment in network technology in preparation for implementing CPOE.

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48 Birkmeyer CM, Bates DW, Birkmeyer JD. Will electronic order entry reduce health care costs? Effective Clinical Practice 2002;5:67-74.
49 According to the 13th Annual HIMSS Survey, 91% of respondents reported that a high-speed network is currently in place at their organization.

Many hospitals have in place some form of existing **clinical information systems** and upgrading these systems is the highest priority for many organizations.[50] At one extreme, implementing CPOE functionality may require minimal additional upgrade of current systems (e.g., if CPOE functionality is built into the existing software, but has not been configured and implemented in use). At the other extreme, an organization's leadership team may determine that they need to replace all of their principle clinical applications with a different vendor product suite in order to implement CPOE. The corresponding costs in these two situations will differ greatly.

Another related consideration is the **degree of system integration** that exists, and the amount of effort required to establish information flow between the CPOE system and other applications. The CPOE system must be able to send data to, and receive data from, many other hospital information systems, such as the laboratory, pharmacy, radiology, admission/discharge/transfer, patient registration, and other systems. Doing so requires building software "bridges" or interfaces between the different systems, or use of a single vendor, multi-system integrated suite of products designed to allow these different components to communicate with each other without interfaces. Some organizations have in place clinical applications from multiple vendors; if a CPOE system is inserted into such an environment, software interfaces must be constructed between CPOE and other systems. In these cases, interface construction could contribute significant costs. Alternatively, use of an integrated system (or one that at a minimum integrates CPOE, pharmacy fulfillment and nursing documentation) may preclude the need for constructing costly interfaces to achieve a fully functioning decision support system, but in some cases this would require organizations to de-install current applications, then purchase and install a full suite of new applications to achieve this integration. Our case studies contain examples illustrating all of these scenarios.

Hospital setting: academic vs. community hospital. The challenges of persuading community-based physicians to use CPOE are generally assumed to be much greater than for resident house staff who spend most, if not all, of their time in an inpatient setting which is usually at a single hospital. They may be more accustomed to using computers in clinical care than their community-based counterparts who spend more of their time in the ambulatory environment. On the other hand, some CPOE costs could conceivably be lower if the community hospital's clinical systems environment is less complex. Given that the challenges and costs of CPOE implementation in the community setting could differ significantly from those in the academic setting, we also included one community hospital in our study.

Case Study Selection and Approach

For this study, we selected five sites that have successfully implemented CPOE within the past five years. "Successful implementation" was defined as having 50% or more of physicians using CPOE for medication ordering; and a CPOE system currently operating at least two of the elements of clinical decision support defined by The Leapfrog Group's

50 According to the 13th Annual HIMSS Survey, 42% of respondents said that upgrading inpatient clinical systems was a top priority for them within the next year; 74% said that clinical information systems are the most important application needed over the next two years.

published CPOE evaluation standard.[51] Only organizations that had implemented commercially available software systems were considered.

We sought to include a community medical center, as well as academic medical centers, and to represent several software vendors. In addition, we included one site that implemented a CPOE pilot and, after encountering difficulties, chose to halt the rollout and reassess their approach. Organizations were solicited through First Consulting Group's hospital contacts, including the Scottsdale Institute, and with assistance from the American Hospital Association and the Federation of American Hospitals.

The following organizations contributed case studies:

- **Boston Medical Center** (BMC), a 547-bed urban safety net hospital and community care provider. Boston Medical Center implemented the Eclipsys CPOE system starting in 2000 with the goal of transforming care delivery and clinical operations and improving care quality and medication safety in particular. As of late 2002, CPOE is operational across all inpatient settings and 99% of all inpatient orders are entered electronically. BMC cited unequivocal support from senior leadership and ongoing involvement of influential physicians and nurses as central to the effort's success.
- **Lehigh Valley Hospital and Health Network,** located in the Allentown-Bethlehem region of Pennsylvania, where most care is provided by community practitioners. Their goals were to eliminate handwriting of prescriptions, improve safety in general, and reduce inefficiencies resulting from the need to clarify unclear orders. Pharmacy orders were previously being entered using IDX Corporation's integrated hospital information system but not by physicians. CPOE entailed primarily changing clinician workflow and addressing physician cultural barriers to physician use of the system. The predominance of independent community practitioners at the hospital made this challenging. Use of a near-full-time physician advocate and heavy use of educators to work with the community physicians have proven useful in promoting adoption. Implementation is underway at their largest (600-bed) hospital. As of late 2002, over half of the care units are operating CPOE and most physician orders are placed online.
- **Main Line Health,** in suburban Philadelphia, where CPOE implementation was halted after a pilot test revealed unanticipated difficulties. The organization attributed the pilot's lack of success to a variety of factors including failure to

[51] Kilbridge P, Welebob E, Classen D. Overview of the Leapfrog Group Evaluation Tool for Computerized Physician Order Entry. The Leapfrog Group, 2001, www.leapfroggroup.org. The CPOE system must operate at least two of the following elements of clinical decision support:

- Therapeutic duplication alerts
- Single and cumulative dose limits
- Drug-allergy interaction alerts
- Contraindicated route of administration alerts
- Drug-drug interaction alerts
- Contraindication/dose limits based on patient diagnosis
- Dose limits based on patient age, weight
- Contraindication/dose limits based on laboratory studies
- Corollary order recommendations in active use
- Cost of care recommendations

assign sufficient resources to the project, inadequate designation of the project as a top priority, and inadequate communication between leadership, designers, and end users. The organization is still moving forward to implement CPOE but is reconsidering their approach in light of this experience.

- **Ohio State University (OSU) Medical Center,** located in Columbus, Ohio, where the Siemens CPOE system is implemented at three of their inpatient facilities representing a total of 684 beds, as of late 2002. The team performed extensive customization of the product to meet production requirements. They have implemented a very large number of organization-designed order sets for all aspects of care, including oncology chemotherapy.
- **Queens Health Network**, located in the New York borough of Queens. The organization's goals were to improve care documentation and access to information, as well as quality and efficiency of care delivery. Queens Health Network implemented the Per Se integrated system, previously selected as the system of choice by parent New York City Health and Hospitals Corporation, and began implementation in its ambulatory centers. At the end of 2002, CPOE is in use at both of the network's hospitals with a total of 771 licensed beds, as well as at 17 community health centers and school clinics.
- **The Hospital of Saint Raphael,** located in New Haven, Connecticut, is a 511-bed center affiliated with Yale University School of Medicine. Their decision to implement CPOE was tied specifically to patient safety concerns arising from the 1999 Institute of Medicine report on medical errors.[11] Like Lehigh Valley, pharmacists at Saint Raphael's previously entered medication orders into an integrated system (Per Se Systems); CPOE implementation required modification of the user interface for use by physicians and nurses. Simultaneous implementation of an electronic medication administration record (MAR) added greater value to the CPOE implementation in physicians' eyes by giving them electronic access to patient medication profiles. Other keys to success were solid leadership by the Medical Executive committee and around-the-clock deployment of a "SWAT team" of red-vested user assistants on the wards, available immediately to help physicians and nurses with problems and questions. As of late 2002, over 90% of units are operating CPOE and over 95% of orders are entered electronically.

The organizations studied participated in two to three interviews each where they described the history of their CPOE initiative, including timing, vendor selection, implementation approach, obstacles encountered and lessons learned, and current status. The organizations also completed a spreadsheet representing cost data, application suite, and extent of system interfaces or integration. The categories of expenses are listed in the table on the following page. The contributing organizations reviewed the completed case studies to ensure that the data and narratives accurately portrayed their experience.

Summary of Expense Categories Used in Quantifying CPOE Implementation Costs

One-Time Capital Costs
Hardware/Server Costs
Software License Costs
Network (LAN, WAN, and telecom)
Workstations/Printers
Interfaces
Conversions
Vendor Implementation
Contractor/Consulting
Implementation Travel Expense
Disaster Recovery
One-Time Operating Costs
Internal Project Teams
IT Management
Project Manager
Analyst
Technical (server/network/hardware)
Integration (interfaces)
Database
Non-IT Resources
Executive Leadership Input
Clinical Resources (non-IT)
Physician Resources
Temporary / Replacement Staffing
IT Resources
Clinical Resources (non-IT)
Physician Resources
Training Resources
Other
RFP/Selection Costs
On-Going Costs
Technology Costs
Hardware Maintenance
Software Maintenance
Interface Maintenance
Network Maintenance
Workstation Maintenance
Annual Disaster Recovery Costs
Staffing Required to Maintain CPOE Following Implementation
Database
Help desk resources
Project Manager
Analyst
Technical (server/network/hardware)
Integration (interfaces)
Training
Non-IT Resources
Clinical Resources (non-IT)
Physician Resources

General Observations from the Case Studies

The five case study sites implemented CPOE across a wide variety of environments including intensive care units, rehabilitation hospitals, community, and outpatient settings. All used commercially available vendor products. Several organizations have implemented ordering for very complex order types including oncology chemotherapy and HIV therapy, and all are operating basic decision support for medication safety. While it is too soon to quantify all of the potential benefits gained, these five sites consider themselves CPOE success stories.

The timeframe for the implementation of CPOE at the study sites ranged from one to six years and is shown in the following table.

Timeframe for CPOE Implementation at Study Sites

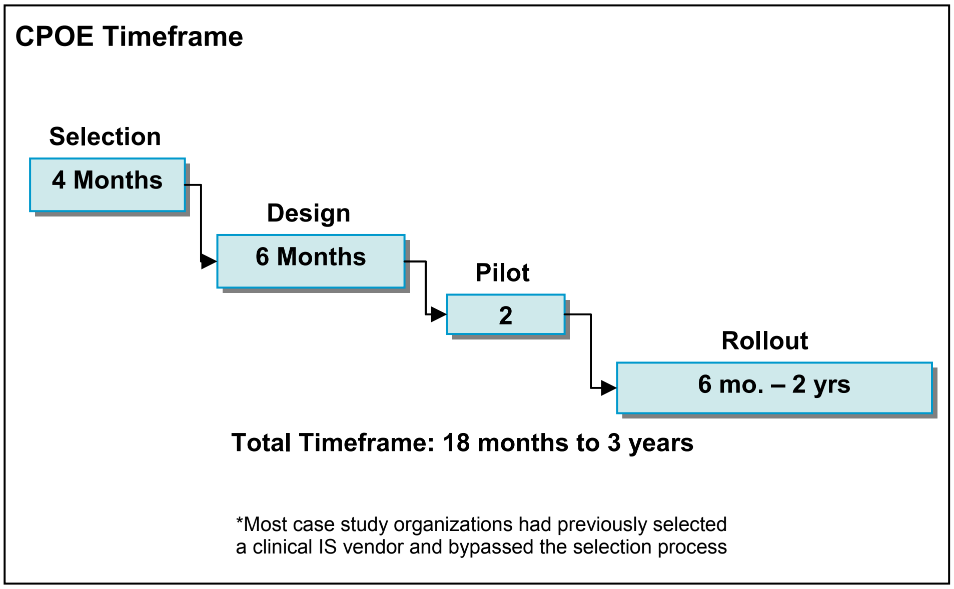
Organization	Approximate Duration of Implementation*
Boston Medical Center	<2 years
Lehigh Valley Hospital	2 years
Ohio State University Medical Center	2 years
Queens Health Network	1 year**
The Hospital of Saint Raphael	1 year

**4/5 organizations have reached >90% implementation (Lehigh Valley >50%) as of December 2002*

***CPOE was implemented at the organization's two inpatient facilities in less than 1 year; ambulatory care sites had been implemented during the first year of the project six years prior.*

Four of the five organizations had implemented CPOE throughout 90% or more of their inpatient units, and over 90% of orders were being entered electronically by physicians at the time of this writing. Queens Health Network spent six years total implementing multiple ambulatory care sites, followed by two hospital implementations, but both hospitals were implemented during calendar year 2002. In addition, it should be remembered that both Saint Raphael's and Lehigh Valley Hospital implemented CPOE on a previously installed clinical information system, which presumably reduces implementation time. A generic summary of the steps involved in CPOE selection and implementation is shown in the following diagram.

Typical CPOE Implementation Steps and Timeframe



Analysis: Costs of CPOE Across the Sites

The range and average of the principal components of one-time capital, one-time operating and ongoing operating costs for CPOE across the five sites are shown in the following table. Total one-time combined capital and operating costs ranged from $6.3 million to $26 million with an average of $12 million.

Range and Average Costs of One-Time and Ongoing Costs of CPOE Across Five Sites

Type of Cost	Low	High	Average
One-Time Capital Costs	$478,080	$18,600,000	$7,400,000
One-Time Operating Costs	$1,436,200	$8,752,500	$4,609,575
Total One-Time Costs	$6,297,280	$27,352,500	**$12,010,680**
Annual Ongoing Operating Cost	$370,450	$3,057,800	**$1,500,000**

Determinants of Total One-Time Cost of CPOE

The factors that exhibited the greatest impact on the cost of CPOE implementation were the size and complexity – particularly the number of sites – of the implementation, and the extent to which organizations had to acquire additional hardware and software beyond what they had already installed.

The largest and most expensive CPOE project among our case studies, Queens Health Network, was executed across a combined ambulatory and inpatient health network totaling 17 separate sites (15 clinic sites plus two separate hospitals). In addition, the organization implemented a single comprehensive, integrated clinical information system, including laboratory, pharmacy, radiology, clinical documentation, emergency department and other modules in addition to CPOE. Clearly, some of the cost figures for that effort (particularly the network investment) will be less representative of costs for CPOE efforts limited to the inpatient setting.

The organization with the lowest one-time and ongoing costs for CPOE was Lehigh Valley Hospital and Health Network. This community hospital network implemented CPOE at one hospital, and rollout was just over 50% complete at the time of this writing. More important, however, their CPOE implementation consisted essentially of expanding the use of the existing order entry application, which had been in use for ordering by nurses and pharmacists for years, to physician ordering. While this organization invested considerable resources in managing the transition to physician ordering, their additional capital costs were nominal, beyond expanding their wireless network and purchasing wireless devices.

Cost Breakdown: Where the Money is Spent

Selection. Of the five organizations that successfully implemented CPOE, three chose to stay with their existing information system vendors and did not engage in the selection of a new vendor. Neither of the two remaining organizations conducted an extensive selection process, and thus no organization spent more than $15,000 on vendor selection. It is worth noting that this may not be representative of the industry; some organizations spend many times this amount during vendor selection.

Capital costs. Predicting capital costs will depend on an organization's pre-CPOE baseline status. For example, at two organizations in our study, **network upgrades** accounted for more than one-fifth of their total one-time costs. The upgrades that these organizations undertook for CPOE might have otherwise been required to support other system initiatives anyway since a majority of hospitals have already implemented high-speed computer networks. [48] Thus, if a hospital considering CPOE has recently upgraded their network infrastructure, this category of costs could be a fraction of that spent by these two organizations. The capital investment that each case study site allocated for CPOE (as a percentage of their average annual capital dollars) ranged from a low of 12% to a high of 166%.

Network expenses may include costs of implementing or upgrading a **wireless network** and purchasing **wireless devices,** which increasingly appears to be an important component of many (but not all) successful efforts. Three of the organizations in our study spent between $400,000 and $1.2 million on purchase and implementation of wireless technology specifically for use in CPOE and/or electronic medication administration record (MAR), for use at from one to three sites. Whether or not a wireless network is in use, additional **workstations** were purchased by study sites to provide adequate end-user access to the system. Two of our case study sites spent approximately 20% of their capital budget for CPOE on workstations.

Among the four organizations that incurred additional costs in software licensing (excepting Lehigh Valley, as discussed previously), the costs of **software licensing** ranged from 6% to 25% of capital costs, or 4% to 20% of total one-time costs. Overall, however, while software costs are perhaps the least predictable element in the total cost equation, in no case did they constitute the largest single capital cost to an organization, surpassed by network, workstation and mobile device costs in all cases.

Operating costs of implementation. The costs of implementation were captured primarily in one-time operating costs, plus the capital categories of vendor implementation and contractor/consulting. They include the costs of both technical resources and executive and physician resources. User training costs are generally included in this category, although one organization capitalized some training costs that were included in their overall software license fee. These costs varied greatly among organizations, depending on a variety of factors.

Investment in Information Technology (IT) team resources ranged from $1.5 million to $4.3 million across the five organizations. Those organizations implementing CPOE at a single hospital spent between $1.5 and $2.1 million. Analysts constituted by far the single highest cost category of resource.

Executive and physician input are particularly important to CPOE implementation, and here we found costs to vary dramatically. The Queens Health Network invested most heavily in these resources, spending $3.9 million over 5 years (this is not surprising given the vast extent of their implementation). More surprising perhaps is that Lehigh Valley invested $2.8 million in these leadership resources. This is likely a result of the extraordinary challenge inherent in persuading community physicians to adopt computerized ordering and the corresponding importance of extensive, visible participation by leaders.

Ongoing costs. The five organizations are spending annually between 6% and 20% of their total one-time implementation costs for ongoing support, revisions and maintenance. Three of the five organizations' annual ongoing costs range between 11% and 13% of their total one-time implementation costs.

Model: General Predictors and Ranges for Costs of Implementing CPOE

From the previous discussion and review of the complete data from the five organizations, we can estimate a cost range for a single hospital of the approximate size and characteristics of some of those in our study group. We can then consider some of the more important variables and how they would likely modify this baseline cost estimate.

The baseline case considers an organization with the following characteristics:

- Implementing CPOE at a single hospital of approximately 500 beds and 25,000 admissions annually
- House staff and academic faculty perform most ordering
- Implementing across all inpatient care units including intensive care units, excluding emergency department
- No need for network infrastructure upgrades
- No wireless network of devices, but want to implement wireless network
- Implementing a newly purchased, currently available vendor product designed for CPOE (not currently operating pharmacy or nursing order entry), with other principle clinical systems already in place
- Implementing either a CPOE product that will require interface construction to laboratory, pharmacy, and radiology systems already in place, or implementing an integrated system that includes CPOE and pharmacy
- Costs do not include purchase of other major clinical or business applications beyond these.

For such a hospital the following approximate costs are projected:

Predictive Costs for CPOE Implementation and Ongoing Support

Category	Cost
One-Time Capital	
Hardware/server costs	$750,000
Software license costs	$900,000
Network (LAN, WAN, Telecom)	$1,100,000
Workstations, printers, wireless devices	$1,100,000
Vendor implementation assistance and/or contractor/consulting	$800,000
Other	$200,000
Total One-Time Capital	*$4,850,000*
One-Time Operating	
Information systems department project team and leadership resources	$2,300,000
Non-IT resources: leadership, physicians, other clinical resources	$650,000
Other	$100,000
Total One-Time Operating	*$3,050,000*
Total One-Time Costs (Capital plus Operating)	**$7,900,000**
Annual Ongoing Operating Costs	
Hardware, software, workstation, network, interface maintenance	$400,000
Staffing to maintain and upgrade CPOE: IT resources	$800,000
Non-IT clinical resources	$150,000
Total Annual Ongoing Costs	**$1,350,000**

The network figure reflects the cost of implementing a wireless network; the workstation figure reflects the cost of purchasing wireless devices plus additional workstations.

Likely Category Variations from the Baseline Model

Hospital size. Among our case studies, some costs vary with the size of the hospital, approximately in relationship to total number of CPOE beds. These include workstations, plus, in some cases, hardware, network and software license costs. Other costs, such as IT and clinician resource requirements varied far less with change in hospital size.

Number of sites. The number of sites had a greater, but by no means linear, effect on capital costs. The number of workstations and network costs were most directly influenced by the number of sites. However, hardware and software license, and non-IT implementation resource costs varied surprisingly little among single versus multi-site organizations in our study. Indeed, software license costs at Queens Health Network – with two hospitals and 15 separate clinic sites – were only twice the cost of one single site hospital, in spite of the fact that QHN's costs included the implementation of lab, pharmacy, radiology, emergency department and other applications. IT implementation costs at QHN were of the same order of magnitude as several single-site organizations.

Baseline network status and need to implement wireless network. Three of our five case studies chose to implement wireless networks to support CPOE implementation (and a fourth is planning to do so). For this reason, we have included the cost of implementing a wireless network in our model. We have also assumed that the baseline cabled network infrastructure is adequate to support CPOE volumes and performance. Costs will be higher if it is not.

An organization with an adequate existing hard-wired network that chooses not to implement wireless computing may spend approximately $1,000,000 less on network costs than cited previously.

Implementation of multiple clinical applications. As discussed previously, at one case study site, the purchase of an integrated software solution for multiple applications added only modestly to overall software licensing costs. IT implementation resource costs were only approximately 50% higher than for several other organizations that implemented only a single major application (the CPOE system). If an organization that uses non-integrated clinical systems (e.g., from a variety of vendors) needs to purchase or replace multiple applications (laboratory, pharmacy, radiology, etc.) before implementing CPOE, the overall costs could exceed those in the model.

Two organizations studied had previously implemented an integrated clinical system in which CPOE functionality was present, but not in use by physicians for ordering. Rather, both had pharmacists entering orders. An organization in this specific situation may be able to drastically reduce the capital costs of the effort, especially hardware and software costs. Implementation costs may or may not be reduced depending on the degree of application redesign required for physician users.

Academic versus community hospital setting. One of the greatest areas of concern in discussions about the costs and challenges of implementing CPOE is that of the community hospital environment, where community physicians rather than house staff perform the bulk of the ordering. It is generally assumed that community physicians will be less willing to take on the challenge of CPOE with its training and often increased time requirements in the ordering process.

It is risky to generalize from a single case experience, but several observations can be made by comparing Lehigh Valley and the four academic sites studied here. As mentioned previously, the most striking difference between Lehigh Valley's costs and those of other organizations was the large investment made in executive leadership and physician resources – approximately two- to four-fold the costs at the other two single-site organizations, and double the average used in the model. Presumably this relates to the need to work closely with the community physicians over time at a peer-to-peer level.

Estimating costs for smaller hospitals. Given these considerations, we can roughly estimate some costs for smaller hospitals. Roughly speaking, a hospital of 250 beds that otherwise shares the characteristics listed previously for our model hospital might expect to spend closer to $3 million in capital costs, and perhaps $700,000 in annual ongoing costs. Given an absolute requirement for a core project team with requirements similar to that needed for a larger hospital, one-time operating costs will vary less, but likely would range anywhere from $2 million to more than the $3.1 million in the case study site where additional physician and training resources were required to manage the education and training of independent community physicians.

Benefits of CPOE at the Five Sites

The categories of benefits that may result from CPOE use were introduced earlier and include improved medication safety, standardization of care, improved efficiency of care delivery, and cost savings. How have our case study organizations articulated the benefits they expect to derive, and how will they measure these benefits?

None of these organizations stated that they were pursuing CPOE for financial benefits, nor did they expect CPOE to pay for itself. Perhaps the most interesting finding was the degree to which these organizations have been willing to accept that if properly implemented and widely adopted, CPOE is simply the right thing to do and that benefits will accrue even if they are not measured. One physician leader commented that if the value has been well demonstrated by others, it is not clear that every organization has to repeat the pioneers' studies any more than it is necessary to re-test a vaccine that has been shown effective in trials. Another organization's CIO stated, "We were never in it for the financial savings," but rather to improve care efficiencies "and prevent something really awful from happening."

Nonetheless, all of the organizations have chosen to examine the impact of CPOE in one way or another.

Efficiencies of care delivery. In the early months after completion of CPOE implementation, process efficiencies are the most easily studied since doing so doesn't require accumulating and analyzing data over long periods of time. Most of the early results from our study group fall into this category. Thus far, the organizations have limited documentation of savings, though all have plans for further study. OSU has taken the most formal approach, examining the impact of CPOE implementation across the first two hospitals to go "live." Using pre- and post-implementation measurements, they were able to demonstrate statistically significant reductions in medication turnaround times (from order to administration) of 64%, radiology procedure completion times were reduced by 43%, and laboratory result reporting times were shortened by 25%. In addition, they demonstrated a significant improvement in compliance with co-signature of verbal orders (important for regulatory compliance), and a small, but statistically significant, reduction in length of stay at one of two hospitals.[52] In addition, they plan to track duplicate test ordering.

Lehigh Valley is planning to employ ethnographers to study pre- and post-implementation work processes and time requirements for various aspects of care delivery.

Saint Raphael's indicated that they are hoping that efficiencies generated by CPOE will assist them in dealing with their nursing shortage, which is limiting the number of beds they can keep in operation. They do not expect to reduce the number of nurses needed at the hospital, but instead hope that, by reducing length of stay and accelerating bed turnover, they will be able to increase the total number of patients they can treat with the existing supply of staffed beds. Saint Raphael's has already observed a decrease in medication turnaround time from over two hours to 18 minutes. In addition, pharmacists

[52] Mekhjian HS, Kumar RR, Kuehn L, et al. Immediate benefits Realized Following Implementation of Physician Order Entry at an Academic Medical Center. JAMIA 2002;9:529-539.

have more time to provide clinical consulting on the care units and medications are being switched from intravenous to oral administration earlier.

Boston Medical Center noted an anecdotal observation of another kind of efficiency: The use of the system has resulted in a reduction in the number of telephone calls between pharmacy, nursing, and ancillary staff as the CPOE system permits the easy tracking of order status and clear communication of orders, reducing the need for clarifying phone calls.

Cost savings. Closely related to efficiencies of care delivery, but harder to demonstrate and attribute to the CPOE system, are specific dollar cost savings or new revenues. As is expected with organizations that have recently completed CPOE or are still in the process of final rollout, the study organizations had limited data in this area. Nonetheless, several participants have documented early cost savings.

Queens Health Network has saved approximately $270,000 annually through elimination of transcription costs and increased radiology revenues by over $300,000 annually through better capture of documentation with CPOE. Savings such as these contribute to offsetting a site's implementation costs. Lehigh Valley has also begun tracking data on radiology costs and reimbursements and they are observing improvements in efficiency and an increase in revenues. Boston Medical Center has documented $50,000 in annual savings due to earlier conversion from intravenous to oral medications.

Improving medication safety. Given the importance of patient safety as a driving factor for CPOE implementation for all participants, we might expect more attention to be directed at documenting the impact of system use on medication errors and ADEs. As stated earlier, the study organizations agreed that the case for CPOE improving medication safety has already been made. Boston Medical Center measured and detected a decrease in prescribing errors as measured by voluntary reporting, and OSU demonstrated a decrease in transcribing errors on those units where an electronic MAR had been implemented.

Care standardization. Several organizations have begun to track adherence to order sets and care guidelines and advice. OSU currently tracks order set utilization and Queens Health Network is planning to track appropriate use of medications and tests. More significant, Queens will track a series of both process and outcome indicators of community health quality around conditions such as chest pain, diabetes, depression, and asthma management.

The following table summarizes the areas of benefit that each organization is targeting to study through their implementation of CPOE (though given their relatively early implementation, specific benefits may not yet have been achieved):

Planned Post-Implementation Benefits Measures for Case Study Sites

	BMC	Lehigh Valley	OSU	Queens	Saint Raphael's
Process Efficiencies	✓	✓	✓	✓	✓
Cost Savings	✓	✓		✓	
Medication Safety	✓		✓	✓	
Standardization of Care			✓	✓	✓

Given the recent (or in some cases, pending) completion of CPOE implementation at these sites, it is not surprising that they have accumulated relatively little benefits data to date. It would be instructive to revisit these organizations in the future to learn more from their experiences.

Challenges and Lessons Learned

The case study organizations' stories echo many previously described findings regarding important success factors for CPOE.[29,36,37,44,45] A shared vision among executive leadership both clinical and administrative; allocation of sufficient dedicated resources to see the project through planning, design, and implementation; involvement in the effort of one or more dedicated physician champions; an abundance of 24x7 on-the-ward user support during the first weeks after rollout; and achievement of rapid response times and user-friendly interfaces were cited by most or all participants as critical to their success.

Our one case study organization that halted implementation of CPOE carries some important lessons, including in particular the need to designate and commit adequate resources to the effort. Their story is described at more length on the following page.

Main Line Health: A Pilot Implementation

Main Line Health is a four-hospital delivery system in suburban Philadelphia. The organization's medical executive leadership decided to implement CPOE in 2000, citing the potential for patient safety improvement. They chose to begin with a pilot implementation on the labor and delivery unit at one hospital. The pilot project was in part an experiment designed to determine whether Main Line would commit to CPOE with their current vendor. The effort had support from the medical leadership with strong steering committee representation, including the Chairman of Medicine, Vice President of Medical Affairs, a senior OB-GYN physician and Chief Resident, Senior Vice President for Nursing, and a clinician liaison to Information Technology. However, the effort encountered obstacles and the organization elected to take down the system after four weeks operation and reconsider their approach to CPOE.

What did they learn? First, the project was treated as essentially an IT department project rather than a broader organizational effort. The pilot care unit had developed many physician order sets, and their implementation was thought of as technical, rather than requiring significant workflow redesign. Expectations were high, and the effort required to implement was underestimated.

An inadequate number of dedicated staff were assigned to the project; pharmacy and nursing resource requirements in particularly were underestimated. In addition, while individuals were assigned the necessary designated tasks, they were not relieved of other responsibilities, nor was it communicated that their CPOE work was a top priority. The organization also felt that the vendor implementation team was inadequate to support the necessary tasks.

Technical challenges encountered included difficulties with implementation that prevented communicating data from CPOE to the pharmacy system, and problems with interspersing orders from the Labor and Delivery unit with orders from the rest of the hospital, which were not communicated by CPOE.

While the implementation team performed a full system design and walk-through prior to building the system, there were gaps in the education of, and communication with, the physician house staff. Physician training was not made mandatory, although use of CPOE was. In addition, the house staff preferences for ordering format were misinterpreted and improperly designed into the system.

It soon became clear that the changes to the system required to make it function adequately exceeded the resources available in the IT department, and leadership decided to halt the implementation and remove the system. The organization ultimately chose to revisit the question of vendor selection. In the end, they chose to remain with their current vendor but wait for their newest generation of software to become available. They also decided to begin implementation next time starting with order entry in the pharmacy and move to physician ordering as a second step.

A number of new findings of potential best practices emerged during this study. These include:

Rapid design process. Both OSU and Queens Health Network cited use of rapid cycles of software design as key to meeting user needs during the design and implementation phases. While iterative design processes have been used for some time by organizations implementing new systems, the formal adoption of a design methodology incorporating multiple user disciplines has not often been discussed in the literature on CPOE. It represents an important addition to the best practice literature for a couple of reasons.

First, use of a rapid design process – a formalized approach to design, prototyping, redesign, testing and rollout of software systems – greatly facilitates the adaptation of vendor systems to specific user environments. When a vendor system is inserted into an operating clinical environment, some degree of site-specific system configuration is required to meet the performance requirements of clinician users in a live CPOE environment. This was a common theme among our case study participants. Redesign ranged from subtle tweaking of the application to radical redesign of the interface and functions.[46] Second, the product must generally be redesigned and tested repeatedly through a series of several prototypes during implementation. When preparing and then adapting the system to use in clinical care, these design/test/redesign cycles must occur very rapidly in order to address critical user needs and not alienate the user base with long delays. Anticipating in advance that such a complex iterative and multidisciplinary approach will be required, and adapting a formalized methodology for doing so, makes for more accurate forecasting of resource and end user time requirements and costs.

Education. The experience of the single community hospital participant offers a hint of some of the requirements for implementing CPOE in an environment where independent community physicians, rather than house staff, do the bulk of the ordering. Mandating use of CPOE is unlikely to succeed; and the organization must rely on persuasion rather than edict from the clinical leadership. Education, therefore, plays an even larger role here than in other settings. Lehigh Valley hired three full-time educators, in addition to one physician and two full-time nurses, to address this issue. To encourage adoption by independent practitioners, the organization chose to support the use of physician-specific custom order sets – something that other organizations generally discourage. Provision of wireless access and mobile devices also proved crucial to success at this organization, permitting physicians a greater degree of flexibility and freedom from unit-based workstations.

Nursing support. In the community setting, there may be great value in placing heavy reliance on a well trained nursing staff to manage and support physician use of the system. This fits with the role of nursing in the community hospital in general; as community physicians spend less time in the hospital than residents, the nurses are accustomed to operating more independently in day-to-day patient care. Lehigh Valley placed a strong emphasis on nursing training in the use of the CPOE system, and led the CPOE implementation with installation of an electronic MAR, which facilitated nursing's transition to electronic medication management. This approach may prove useful in other hospital environments characterized by a strong nursing culture.

Online order sets. Several of our participating sites emphasized the importance of early design and construction of online order sets during implementation, to facilitate rapid adoption of the system. OSU actually mandated that the principal departmental and environment-specific order sets be drafted, approved by departmental leadership and coded into the system prior to implementing the system in each environment.

Conclusions

Our targeted study confirms the general perception that CPOE is costly and that the range of costs for a specific organization can vary considerably depending upon a number of factors. The average one-time cost to the five study organizations was over $12 million. After adjusting for extraordinary factors at several organizations, we arrived at a baseline figure for a single medium-large hospital implementation of $7.9 million. Annual ongoing costs are about 17% of one-time costs.

Beyond variations in investment required according to organizational size and number of applications implemented, the cost of wireless network implementation stands out as a significant expenditure for many organizations that choose to make use of this technology. In the community setting, additional costs may be incurred for investment in clinician and administrative leadership efforts. Our model may be used as a starting point for discussion of probable costs by organizations considering a CPOE implementation.

The participants in our study consider that the quality benefits offered by CPOE are clear and are focusing their current and future plans on measuring the efficiency gains and improvement in care standardization. These organizations have only recently completed implementation (or are still doing so) and a future examination of their findings will be informative.

The study sites believed that patients are the primary beneficiaries of CPOE through improved safety and quality of care. It is important to note that any savings realized from efficiency gains and care standardization can accrue either to the hospital – when hospitals are paid per case (e.g., Medicare) – or to the purchaser – when hospitals are paid based on discounted charges or per diem rates. CPOE investments to date have mainly been financed by hospitals themselves, though there are some early experiments in which other entities are contributing to funding of CPOE and other quality efforts.

The study participants confirmed many of the known challenges, best practices, and requirements for success in implementing CPOE. Factors cited as crucial to the organizations' success include: a shared vision among executive and clinical leadership, dedication of resources through the project life cycle, engagement of physician champions, intensive user support during implementation, rapid computer response times and user-friendly interfaces. In addition, they underscored the value of employing a software design methodology during implementation that is rapid and iterative as key to responding to user needs. The preference for wireless network environment for encouraging CPOE adoption was also echoed. Lastly, emphasis on the use of nursing staff and other ward staff to assist physicians during CPOE rollout may prove to be a best practice in the community hospital environment.

In summary, CPOE is achievable in a variety of physical and technical environments using currently available vendor software, but is also very resource-intensive, time consuming, and expensive. This study provides organizations with a useful model for beginning to estimate how challenging and expensive the undertaking will be in their particular case.

Appendix:

Case Studies of Completed Implementations

Boston Medical Center

An academic medical center affiliated with Boston University's School of Medicine, Boston Medical Center (BMC) was formed by the merger of BU's University Hospital and Boston City Hospital. Today the 547-bed BMC sees about 25,000 admissions a year. The medical center also provides over $200 million in uncompensated care to surrounding communities, making it the largest safety net hospital in the region.

Origins and Goals of the CPOE Initiative

BMC's Chief Information Officer, Meg Aranow, came to the organization from Boston's Brigham & Women's Hospital, where she had been intimately involved in the design and implementation of that organization's CPOE system. Based on her past experience, Aranow felt from the outset that BMC should move toward CPOE. Her vision was shared by BMC's Chief Medical Officer, Chief Executive, and Chief Financial Officer, all of whom later proved instrumental in championing the effort. This leadership group believed that CPOE could help BMC to achieve four principal objectives:

- Reduce adverse drug events;
- Improve care quality in general;
- Standardize care across two recently merged institutions; and
- Contribute to BMC's image as a top tier institution in the eyes of both patients and potential physician recruits.

The hospital selected a CPOE system in 1998, choosing Eclipsys Sunrise Order Entry. Planning for CPOE implementation commenced in early 2000, and the system was pilot tested at the end of the year. Aranow chose to test the system on one of the hospital's busiest medical-surgical units, with the goal of challenging the system with a wide variety of complex order types. Following a two-week pilot period a number of modifications were made to certain medication orders. A full-scale rollout was commenced at the beginning of 2001 and completed 17 months later, in the spring of 2002. At the time of this writing, CPOE is operational across all inpatient settings including intensive care units. Only oncology chemotherapy orders are still written manually, and automated chemotherapy order sets are under construction. Overall, 99% of all inpatient orders are entered electronically. In addition, through construction of interfaces to laboratory, radiology, pharmacy, pathology and dietary, they have effected electronic order communication (and thereby eliminated transcription) for 91% of ancillary orders.

Challenges and Keys to Success

While there were certainly a number of outspoken physician opponents, most of the physician staff were familiar with the Brigham & Women's experience and the arguments supporting use of CPOE to improve clinical quality and were supportive of the effort. For those few opponents who continued to resist implementation, a clear top-down directive from senior leadership ultimately achieved compliance. A number of influential physicians and a nursing director also played central roles in championing the project.

Some of the obstacles encountered were logistical and technical. For example, a shortage of physical space on the wards for the additional PCs required was a significant problem. Through rearranging space and equipment, the IS department managed to place enough PCs on the care units. They are considering use of wireless units to further alleviate the problem. Another challenge was helping users to work the system's user interface, which required substantial education and training.

The most time-consuming aspect of implementation was user training, particularly choreographing the training of nurses in the use of the system. The need to remove nursing staff in groups from the care delivery units for training necessitated altering nursing schedules to cover for those in training. This process had to be coordinated across all inpatient care environments in a rolling fashion. This task, and creating and scheduling the necessary classroom space, were made even more complex by the involvement of two nursing unions, which demand 30 days' notice of intent prior to making such schedule changes.

Decision Support

Clinical decision support content and direction is determined by a team that includes a nursing manager and two part-time physicians, with input from the Policy and Operations Committee (representing a broader clinician constituency), and the Pharmacy and Therapeutics committee.

BMC has constructed two interfaces between their CPOE and pharmacy systems, allowing electronic communication of orders to the pharmacy and communication of order status to the CPOE system. At present, the medication administration record is generated manually but work is in progress to generate an electronic MAR from the CPOE system. The interface from pharmacy to CPOE will ensure that nurses viewing the MAR will receive the final medication order as signed off by pharmacy – a step critical to ensuring medication safety. A two-way interface has been constructed between CPOE and the laboratory system.

At present, interaction checks and alerts exist for drug-drug and drug-allergy interactions and redundant laboratory tests; and patient weight and route of administration are checked in pediatric orders. Drug-laboratory interaction alerts are being developed. Also in development are duplicate therapy checks.

In addition to the above medication checks, over 275 order sets have been constructed by departments and are in use, although utilization of these has not yet been measured. Physician-specific order sets are permitted but their development is not encouraged.

Other alerts and decision support tools include warnings about look-alike and sound-alike drugs, management of restricted antibiotics, and recommendations for switching medications from IV to PO form when appropriate.

Benefits Assessment

As implementation was completed only months before the time of this writing, benefits assessment is in the early stages. Leadership's highest priority goals for CPOE were to reduce adverse drug events, improve quality, and standardize care, and plans are in place to monitor progress in these areas. The organization has detected a reduction in prescribing errors, as measured by voluntary and pharmacist reporting, but data are preliminary. Some feared an increase in the number of laboratory tests ordered would increase when order sets came into common use, but this did not occur. Utilization of order sets will be measured. Savings just from the single intervention of recommending a timely switch from IV to PO medications has already saved approximately $50,000. In addition, the number of telephone calls handled daily by nursing, pharmacy, and ancillary staff has fallen dramatically. This has occurred because the CPOE system allows easy tracking of order status; staff no longer need to call around the hospital to find out the status of medications, personnel, test scheduling and the like.

Aranow believes that ultimately, the greatest value of CPOE may be the ability it gives leaders to address the entire physician staff as a body, almost immediately, to effect change. Using the system, adherence to a new prescribing policy or care standard can be initiated – and often, realized – almost overnight. Thus, standardization of care becomes not only standardization of clinical practice, but standardization of the care *management* process through CPOE.

Note: The range of costs for implementing CPOE at the case study sites are listed in this report under: ***Analysis: Costs of CPOE Across the Sites.***

The Hospital of Saint Raphael

The Hospital of Saint Raphael is a 511-bed acute care hospital in New Haven, Connecticut, affiliated with Yale Medical School. Saint Raphael's admits approximately 22,000 patients annually. The organization began to implement CPOE in the fall of 2001, and at the time of this writing approximately 90% of all patient care units are operating CPOE.

Origins and Goals of the CPOE Initiative

The hospital leadership's decision to pursue CPOE was triggered by the 1999 Institute of Medicine report, *To Err Is Human.* Their primary goal was to improve patient safety. Concurrent with the CPOE effort, the hospital began implementation of an electronic medication administration record (MAR) to further improve safety of medication management.

Previously, Saint Raphael's was already operating the Per Se integrated hospital information system across all clinical departments. Hospital pharmacists entered all medication orders into the Per Se pharmacy module. As the system was fully integrated, the additional technical work required for CPOE included modification of the user interface for use by physicians and nurses, and the design and programming of the MAR. The design and programming was accomplished during the winter and early spring of 2002. Seven medical care units went live in May, followed by seven surgical units in June; five additional units have been implemented as of October 2002.

Challenges and Keys to Success

The organization expended considerable effort mapping clinical workflows and unit configurations during the 6 months before implementation on the medical units. This process permitted optimal planning for the transition to CPOE. In addition to the extensive training offered to nurses, physicians, and other users of the system, the IS, nursing and pharmacy departments provided round-the-clock, on-the-unit user assistants, who were easily identified by red vests. The "red coats" as they became known were vital to ensuring the success of the implementation.

CMO Charles Riordan, CIO Gary Davidson and their team decided at the onset to create the expectation that both residents and attending physicians would use the system. Saint Raphael's believed that the majority of physicians would comply early on if given adequate assistance. In fact, they quickly achieved over 95% compliance among physicians. The areas of greatest difficulty were those where resident physicians were not part of the workflow, and other physicians wrote orders on patients – such as postoperative environments.

The concurrent implementation of the electronic MAR, while requiring a great deal of additional effort, served to greatly boost physician satisfaction with the IS department's efforts, as it facilitated physicians' access to real-time patient medication lists.

Strong leadership commitment to CPOE was crucial to the effort's success. The medical executive committee endorsed the project early on, and the initiative had the complete backing of the chairmen of the departments of medicine and surgery, as well as senior administrative executives. The Vice President for Medical Affairs played a prominent role in championing the project.

Benefits

Improving patient safety was the primary objective of implementing CPOE, and the senior medical leadership were familiar with the literature of pioneering institutions such as the Brigham and Women's Hospital, which demonstrated numerous benefits of CPOE in quality improvement and cost savings. One leader commented that with the value well demonstrated by others, it was not clear that Saint Raphael's needed to repeat such studies, any more than physicians need to study repeatedly the efficacy of a well-proven treatment whose benefits have been shown. In addition, as the rollout is only a matter of months old, the organization's efforts continue to be directed toward tweaking and improving the system's performance.

Nonetheless, the organization is severely challenged by the nursing shortage, and is operating all staffed beds at full capacity. Leadership is hopeful that the system efficiencies provided by CPOE will improve the overall efficiency of care delivery, ultimately contributing to shorter lengths of stay and improving patient volumes. Preliminary observations show that efficiencies are starting to appear: the turnaround time from medication ordering to delivery to the care unit has decreased from over two hours to 18 minutes; pharmacists have more time to provide clinical consulting on the units; and medications are being switched from IV to PO form earlier than previously.

Note: The range of costs for implementing CPOE at the case study sites are listed in this report under: ***Analysis: Costs of CPOE Across the Sites***

Lehigh Valley Hospital and Health Network

Located in the Allentown-Bethlehem region of Pennsylvania, Lehigh Valley Hospital and Health Network (LVH) consists of three hospital campuses with a total of 700 licensed beds, and four health center locations. The network serves 1100 physicians, 170 of these belong to the Lehigh Valley Physician Group, and the remainder are independent community physicians. LVH is affiliated with Penn State University College of Medicine, and has resident physicians working on some services.

Origins and Goals of the CPOE Initiative

The topic of CPOE came to the fore in 1999 following a meeting of LVH's Performance Improvement Council. At this meeting, the issue of illegible physician handwriting was discussed at length, and the problems arising there from. These included a 25% error rate in radiology orders, inefficiencies resulting from pharmacists and others having to contact physicians to clarify orders, concerns about medication safety, and others. Senior medical and administrative leadership felt that CPOE was the logical solution to this problem and would address patient safety and improve the efficiency of clinical care delivery in general. The CPOE initiative is part of a larger medication safety improvement program, other components of which include a bar code medication administration system, automated medication administration record (MAR), and a bar code laboratory sample management system.

The organization chose to implement CPOE from their existing hospital information systems vendor, IDX. Software implementation was begun in January 2000 as part of a clinical systems upgrade. LVH pharmacists and nurses had been using the IDX ordering module for years to enter all orders; no software revisions beyond the already-planned upgrade were required for CPOE. The pilot unit – trauma care – went live in June of 2000. This unit was selected because it is relatively self-contained, and would be simpler to operate in an isolated fashion during the period of testing. The application was rolled out to additional care units, first at 30-day intervals, then at 10-day intervals. At the time of this writing, just over half of the inpatient units at the Cedar Crest facility are live on CPOE, with completion of rollout anticipated by March 2003. The majority of the physicians admitting to the Cedar Crest hospital have been trained in the use of the system, and over 50% of orders are being entered electronically. Implementation at the other two hospital locations is scheduled for completion by the end of 2003.

Challenges and Keys to Success

As a community hospital network, the largest challenge faced by LVH involved enticing community physicians to use the system. Several measures proved critical to success in this regard.

CIO Harry Lukens hired a senior program manager to head the project on a fully dedicated basis. He also hired a physician to assist almost full time with the CPOE initiative. As a well-known member of the Lehigh Valley Medical Group, pediatrician Don Levick was well positioned to support his colleagues in learning the value and use of the system. Lukens also hired two full-time nurses and three educators. This team was able to work effectively to support system design and rollout.

Lukens and his team determined at the outset that mandating physician use of the CPOE system was not a practical approach in the community environment. Rather, it would be necessary first to demonstrate the usability of the system and second, to persuade physicians to use it by providing them with extensive support and assistance. Accordingly, rollout was accompanied by numerous education sessions, provision of round-the-clock on-site user assistance, and other forms of user help.

A critical success factor was the provision of wireless access to the CPOE system. LVH already operated a wireless network environment, and the introduction of a mobile device proved invaluable in convincing physicians to order on line.

Another foundation for physician support was provided by the heavy emphasis placed on training the nurses in the use of the system. As the decision had been made to implement IDX's electronic medication administration report (MAR), it was decided to roll out the MAR on the units two weeks in advance of CPOE rollout. In this way, the transition to electronic processes is smoothed, as the nursing staff gets accustomed to handling medication orders electronically. The challenge of managing dual processes – with some physicians writing orders on paper, others via CPOE – falls upon the nursing staff. The nurses routinely go through the system patient-by-patient checking for new orders. In addition, all CPOE-entered orders are automatically printed to the nursing station, making it easier to determine whether and when orders have been placed for a patient. The willingness of the nursing staff to manage these complicated transitions, and to support physicians through the process, has been critical to successful implementation.

In another gesture to improve acceptance by the heterogeneous community physician population, LVH committed to building and supporting physician-specific order sets for system users. Departmental order sets are also in use. At present, cancer chemotherapy order sets have not been constructed for the system, although chemotherapy can be ordered electronically.

Decision Support

The LVH CPOE system performs many basic medication interaction checks including drug-drug, drug-allergy, therapeutic duplication, and dose vs. body weight. Single and cumulative dose limits are written into specific rules for some chemotherapy agents. Pediatric doses are checked against patient age as well as weight. Some corollary orders are in use, such as prompts to order laboratory tests when ordering certain medications.

Benefits Assessment

"We were never in it for financial savings," says Lukens, but rather, to improve care efficiency "and prevent something really awful from happening." Having said this, LVH is studying the results of changes in process with CPOE implementation. Several ethnographers are studying work process and time requirements for different aspects of care management pre- and post-CPOE. In addition, data from radiology are accumulating that demonstrate improvements in both efficiency and revenues.

Note: The range of costs for implementing CPOE at the case study sites are listed in this report under: ***Analysis: Costs of CPOE Across the Sites.***

New York City Health and Hospitals Corporation: Queens Health Network

Queens Health Network is the largest provider system in New York City's borough of Queens. The network is affiliated with the Mount Sinai School of Medicine. In addition to 771 licensed beds in two hospitals and 42,000 admissions annually, the QHN runs 15 community medical centers and 6 school clinics that serve an area of 2 million inhabitants. Community care delivery is central to QHN's mission.

Origins and Goals of the CPOE Initiative

In 1996 the organization determined that expansion of their community clinic base was critical to fulfilling their strategic objectives. The strategic business plan called for expansion of neighborhood health centers from the existing four sites to seventeen over the next five years. At the same time they were facing significant problems with access to information at their Elmhurst site, where they were unable effectively to manage patient record availability among their 90 clinics. Further, diverse ancillary and departmental systems at the hospitals were not able to communicate with one another, requiring clinicians to sign on to multiple systems to obtain patient data. The QHN leadership developed an information technology strategic plan to support their strategic business plan objectives. This called for implementation of a comprehensive computerized medical record. The overall goals for the initiative were to:

- Improve quality of care through universal access to information;
- Improve documentation of clinical data across the care continuum,
- Establish a lifetime clinical record; and
- Integrate information from different systems.

CPOE was viewed as an integral part of a comprehensive electronic patient record, and critical to achieving the above goals, through its contribution to documentation and communication of orders and information.

More specifically, the overall electronic patient record initiative was expected to improve quality of care in the areas of:

- Patient safety – through elimination of transcription errors, improving legibility of prescriptions, notes, and other aspects of documentation; and use of alerts to reduce adverse drug events;
- Efficiency of care – through reduction in the number of redundant laboratory tests and improvement of communications among providers;
- Effectiveness of care – via use of health maintenance and other decision support features; and
- Timeliness of care – through better availability of information.

As the greatest need was perceived to be access to information in the clinics, the electronic record (by Per Se Systems), including CPOE, was first implemented in the ambulatory settings in 1997. Elmhurst Hospital (515 licensed beds) was brought live on CPOE in 2002, and Queens Hospital (200 beds) went live in the fall of 2002.
At Elmhurst, CPOE is implemented across all inpatient environments.

Challenges and Keys to Success

The greatest challenge encountered during QHN's electronic record initiative was physician resistance – although this appears not to have been as great as has been reported by others. From the beginning, it was determined that the system would be designed and implemented in a physician-centric manner. For the first year of operation in the ambulatory environment, physicians were the only users of the system; all other clinicians were trained only in supporting roles. Key to successful implementation was the QHN approach to continuous rapid design and redesign based on clinical workflow. The method involves repeated cycles of workflow analysis, application design and software customization, implementation, and feedback, followed by development of documentation and training materials, final testing and refinement, and final implementation. It was the IS staff's ability to respond rapidly to user needs for improvements in an ongoing fashion that won them the users' trust – users came to believe that QHN was committed to making the system work right for them.

Demonstrating immediate value to physicians was also critical to QHN's success. Providing access to previously unavailable integrated patient information was top priority. Simplifying coding into a single data entry task served to ease the burden of documentation. The resulting improved data availability in turn served to encourage physicians to document a wide range of data types including allergies, diagnoses, and procedures – as they knew that the information would now be available to them for all future patient encounters. At the time of this writing, physicians in the ambulatory centers document histories, exams, and treatment plans on the system; and all orders and prescriptions are entered electronically. Electronic order entry provides an easily accessible, longitudinal record of therapies received by each patient, across both inpatient and outpatient environments.

Clinician participation during implementation occurred at all levels. Executive leadership (both administrative and clinical) supported the effort fully. An HIS Steering Committee comprised of heads of service and chaired by the Project Manager oversaw and signed off on the development and implementation process. Most importantly, many nurses, residents, and attending physicians, and participants from the ancillary departments contributed significant time to system testing and feedback. "The physicians have learned to love the system," says Diane Carr, Associate Executive Director. "Recently an attending threatened to cancel clinic because the network was running slowly, and he was refusing to write orders on paper because it takes too long! Five years ago, they wanted to cancel clinic instead of writing orders online. The irony is tremendous."

Decision Support

The QHN CPOE implementation is currently operating many of the basic as well as sophisticated medication error alerts including drug-drug and drug-allergy checking, dose limit checking, therapeutic duplication checks, dose vs. patient age, and drug-laboratory value checks. In addition, many service-designed standardized order sets are in use, including complex chemotherapy and HIV treatment regimens. Physician-specific order sets are not permitted. In addition there are organization-wide standards for clinical documentation.

Benefits Assessment

QHN is planning to study duplicate test ordering and appropriateness of use of tests and medications following CPOE implementation. In addition, as community health is a central part of QHN's care delivery, programs have been developed to track certain community health indicators, specifically, care process and outcome measures around chest pain, diabetes, depression, and asthma management.

The organization has also begun to look at financial benefits to the hospitals of CPOE and the electronic record. Preliminary study shows estimated savings, for example, of $270,000 annually by eliminating transcription costs, and they have realized over $300,000 in additional revenues annually in Radiology thanks to better documentation through CPOE. In addition, they have experienced significant reductions in claims denials, from 35% in 2001 to 21% in 2002 at Elmhurst, and from 43% to 20% at Queens following CPOE implementation. Beyond these measured gains there are unquantifiable savings in efficiency as a result of improved access to information across the organization. For example, over the five years of implementation, the integrated computerized patient record was crucial to the successful expansion of ambulatory patient volumes by 27%.

*Note: The range of costs for implementing CPOE at the case study sites are listed in this report under: **Analysis: Costs of CPOE Across the Sites.***

Ohio State University Medical Center

Located in Columbus, the Ohio State University Medical Center (OSUMC) is comprised of the Ohio State University Hospitals, the James Cancer Hospital, University Hospitals East, OSU and Harding Behavioral Health, and OSU's College of Medicine. OSUMC has successfully implemented CPOE across most of their inpatient environments since 1998.

Origins and Goals of the CPOE Initiative

The goal of implementing a computerized patient record was formulated by OSUMC executive leadership – lead by the CEO and Chief Medical Officer – in the early 1990's, following the release of the Institute of Medicine's 1991 report, *The Computer-based Patient Record.* [53] Measures of success for the CPR and CPOE would be three-fold:

- Implementation of a portable and scaleable system that could function across diverse environments;
- Successfully meeting the needs of the physician as primary user, including supporting best practices; and
- Acceptance by clinicians.

The organization conducted a needs analysis and selected a vendor for the system – SMS (now Siemens) – in 1996. Planning and system design for CPOE began in 1998. Development was put on hold for approximately 18 months as the IS department had to divert resources to prepare systems for Year 2000.

An initial plan to implement CPOE beginning in 1998 was halted after a nine month pilot on a surgical transplant service, in order to re-allocate resources in preparation for Y2K. The effort was recommenced in February 2000 with a two-month pilot on the same unit, followed immediately by a full-scale rollout across the two major hospitals (Ohio State University Hospital and the James Cancer Hospital). This was accomplished over four months in early to mid-2000. Rollout to the three main hospitals was 95% complete by the end of 2001, and today CPOE is in use across the OSUH, James, and the Dodd Hall rehabilitation facility in almost all inpatient units, including intensive care units and oncology units, and women and infant areas.

Challenges and Keys to Success

The senior oversight group for the CPOE initiative was the Leadership Council on Clinical Value Enhancement. This multidisciplinary committee of clinical and administrative leaders' reports to the CEO and the OSUMC Board, and its subcommittees on clinical computing and quality improvement are closely involved in CPOE oversight.

A core project team was selected to develop and implement the CPOE system. It consisted of clinicians representing laboratory, pharmacy, nursing, respiratory therapy, and radiology who were assigned full time to work with the information systems (IS) department on system development. The project team worked with a physician "consultant" team of ten members representing the major clinical services. This team included both attending physicians and fellows. The physicians' departments were compensated for time devoted to the CPOE project.

[53] The Computer-Based Patient Record: An Essential Technology for Health Care. Institute of Medicine 1991.

The IS group encountered heavy initial resistance from early physician users to the "out of the box" configuration of the system as purchased. Extensive software customization was performed to provide the functional requirements outlined by the physician consultant team, and by the end users during piloting and early implementation. Key to achieving this in a timely and responsive fashion was the use of rapid software design principles for prototype development and modification.

The organization also confronted with a lack of expertise – internal and external – in the area of clinical decision support design and development. They worked hard to assemble a core group of in-house resources that proved vital to supporting the heavy customization requirements encountered during system design and implementation.

The IS group determined early on that it was important to standardize as many elements of the system, and resulting work processes, as possible across different environments. Adherence to a consistent user interface was one example. While different departments had different functional requirements for order screens, adhering to a common overall design, ultimately resulted in a more universally user-friendly system. Development of order sets was also approached in a systematic fashion for all departments. The organization insisted that diagnosis-related order sets be developed from practice guidelines that were systematically reviewed by specialist clinicians for cost effectiveness, clinical best practice and usability. Indeed, it became policy not to implement the CPOE system on a nursing unit serving a particular specialty until the necessary order sets had been developed and coded for use. Physician-specific order sets were not permitted. At the time of this writing OSUMC has over 450 standardized order sets in use, including specialized order sets for oncology chemotherapy, intensive care, and rehabilitation.

Decision Support

The clinical computing subcommittee of the Leadership Council has responsibility for developing and maintaining the CPOE system's clinical decision support functions. The system currently features a two-way interface to the laboratory system, allowing both results reporting and use of laboratory values by the decision support system. At present there is no interface to the pharmacy system, which they plan to replace soon.

Functions currently active for preventing medication errors include therapeutic duplicate checking, single and cumulative dose limit checks, drug-drug and drug-allergy checking, contraindicated route of administration alerts, dose-weight checking for some drugs, drug- and dose-vs.-laboratory value checking, and use of corollary order prompts.

As discussed above, standardized order sets – both disease-specific (based on clinical practice guidelines) and treatment-related (based on therapy protocols) – constitute a cornerstone of clinical decision support and quality improvement in the OSUMC system.

Benefits Assessment

Achievement of efficiencies in care delivery is at the heart of the benefits model for OSUMC. Leadership believed from the outset that adherence to best practices in care delivery, improvement of turn-around times, and better adherence to documentation requirements all would contribute to cost reductions, reduced length of stay, and better regulatory compliance. Accordingly, the organization conducted a study to examine whether such efficiencies were being achieved.

The organization systematically examined pre- and post-CPOE:

- Turnaround times for medication ordering, laboratory result reporting, and radiology exam completion;
- Compliance with co-signature of verbal orders;
- Frequency of transcription errors;
- Length of stay; and
- Overall costs.

They found significant reductions in medication turnaround times (64%), radiology procedure completion times (43%), and laboratory result reporting times (25%). Medication transcription errors were completely eliminated on units where an electronic medication administration record (MAR) was implemented with CPOE.

At one of two hospitals in the study, severity-adjusted length of stay was reduced by a small but statistically significant amount (from 3.91 to 3.71 days). An insignificant decrease in LOS occurred at the other hospital. There was no significant impact on overall costs at either hospital.[54]

OSUMC plans to examine frequency of duplicate test ordering and adherence to care pathways in the future.

Note: The range of costs for implementing CPOE at the case study sites are listed in this report under: ***Analysis: Costs of CPOE Across the Sites.***

[54] Mekhjian, et. Al.; "Immediate Benefits Realized Following the Implementation of Physician Order Entry at an Academic Medical Center", JAMIA 2002 Cite Ahmad et al. JAMIA 2002 benefits article.