Review ■

Computer-based Physician Order Entry: The State of the Art

DEAN F. SITTIG, PHD, WILLIAM W. STEAD, MD

Abstract Direct computer-based physician order entry has been the subject of debate for over 20 years. Many sites have implemented systems successfully. Others have failed outright or flirted with disaster, incurring substantial delays, cost overruns, and threatened work actions. The rationale for physician order entry includes process improvement, support of cost-conscious decision making, clinical decision support, and optimization of physicians' time. Barriers to physician order entry result from the changes required in practice patterns, roles within the care team, teaching patterns, and institutional policies. Key ingredients for successful implementation include: the system must be fast and easy to use, the user interface must behave consistently in all situations, the institution must have broad and committed involvement and direction by clinicians *prior to* implementation, the top leadership of the organization must be committed to the project, and a group of problem solvers and users must meet regularly to work out procedural issues. This article reviews the peer-reviewed scientific literature to present the current state of the art of computer-based physician order entry.

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Time is precious. Neither a sick patient nor a busy clinician has a moment to spare. Errors can be disastrous. An incorrect medication or a high-risk, invasive test performed on the wrong patient could prove life-threatening. Money is limited. Any method of eliminating unnecessary steps must be exploited. Communication—transferring the appropriate information to the correct person at the time and place it is required—is vital.

Perhaps the major impact of information management technology on modern society is the way it is changing the manner and ease with which we communicate. For over 20 years, computer-based, direct physician order entry (POE) has been put forth as a potential way to improve communication within the health care process. As early as 1970, when Collen listed several of the general objectives of a medical information management system,[1] he included "to communicate patient data from professionals providing medical care (doctors, nurses, technicians, etc.) into the patient's computer-based medical record, to other professionals (e.g., dieticians), and to hospital services (e.g., radiology)." He specifically stated that "Physicians should enter medical orders directly into the computer" as a means of ensuring quality.

While the logic of eliminating the middleman through POE is easy to comprehend, actual implementation of POE is more difficult than one might imagine [1980[8,9]; 1988[34]; 1990[53]; 1992[73]; 1993[81]]. A small number of institutions have had success, but the vast majority of institutions that attempted POE, as well as corporations that attempted to sell POE, during the 1970s and 80s met with failure of varying degrees. For example, by 1982, Spectra, in conjunction with its hospital clients, had spent over $200 million to create what was only a rudimentary order-entry system when development was halted [1993[75]]. Thus, during this 20-year period, POE was pursued only at truly pioneering institutions. The late 1980s and the early 1990s saw a renewed emphasis on POE owing to several important factors [1993[83]; 1994[85]]. First and foremost are the advances in information management technology, coupled with the concomitant decreases in price that have permitted new approaches to the user interface [1991[64]; 1992[67]]. Second, there has been a significant increase in general

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Affiliation of the authors: Vanderbilt University, Nashville, TN.

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Correspondence and reprints: Dean F. Sittig, PhD, Center for Biomedical Informatics, Eskind Biomedical Library, Vanderbilt University, Nashville, TN 37232-8340.

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computer literacy within the medical profession and among hospital administrators [1993[78]]. Finally, the interest in developing a complete computer-based patient record to increase quality of care and documentation of services, while reducing costs, has brought the need for direct interaction between practitioners and databases to the attention of medical personnel [1991[57]; 1992[72]].

Experience has shown that it is hard to implement POE successfully. One may ask, "Should POE be a goal?" and "Can POE now be achieved outside pioneering institutions?" We attempt to answer these questions by presenting examples of POE implementation efforts. Next, the rationale for, and barriers to, POE are examined. We then identify key system-design issues. The sources for this article include the peer-reviewed scientific literature and published technical reports. Thus, negative results may be underrepresented. Only those aspects relevant to direct entry of orders by the physician, as distinguished from systems to process orders entered by a third party, are included.

Examples of POE Implementation Efforts

An important distinction must be made regarding the fundamental approaches taken by different developers of POE systems. The first attempts, such as those by Technicon Data Systems (now called TDS Healthcare Systems Corp.), were to develop hospital information systems for use by clinicians. They identified POE as one of their primary objectives at the outset. A second group of investigators focused early efforts on developing a computer-based patient record, or on decision-support systems. Direct order entry was then added as an extension. The first group focused upon implementing straightforward POE for inpatients house-wide, while the second group explored more elaborate functionality for small classes of users, in a mixture of outpatient and inpatient settings. Examples of these development approaches are described below.

Technicon Data System (TDS)

In June 1971, The National Center for Health Services Research selected El Camino Hospital, located in Mountain View, CA, to demonstrate and evaluate the Technicon Medical Information Management System [1975[4]]. TDS is a hospital information system designed for use by nurses, physicians, and other health care workers with a goal of expediting the health care process. It was developed and tested on a single nursing station during the five years prior to 1971. At the time, El Camino was a 464-bed, general community hospital serving patients under the care of their private physicians. It did not have an internship or residency program. It averaged over 22,500 admissions per year between 1970 and 1972, with an average length of stay of 5.4 days.

TDS was implemented in phases. The admission department began to use the system in December 1971 [1975[4]]. In January 1972, the first nursing unit came on line for order entry and reporting of results. All nursing stations were activated by October 1972. By October 1974, 78% of the physicians used the system for either entering orders or reviewing results, and 45% of all orders were entered directly by physicians [1975[4]].

Objective studies of the accuracy and completeness of the computer-based order-entry system at El Camino proved POE to be beneficial. Following implementation of POE, errors of omission in medication orders concerning site and route of administration (7.9% initially) and dosage scheduling (1.3% initially) dropped to less than 0.5% ($p < 0.01$). Inclusion of clinical indications for radiologic examinations and electrocardiographic monitoring increased significantly from less than 4% to over 35% of orders examined [1975[4]].

A subjective assessment of the system showed that the physicians who used the system the most were its strongest proponents. This raises the still unanswered question—do they use the system because they like it, or conversely do they like the system because they use it. In general, those physicians who had adopted personal order sets were the most enthusiastic supporters of the system [1979[7]].

These findings were confirmed in another early TDS installation that took place at the New York University Medical Center. In a pre/post-installation study conducted there, investigators demonstrated a 22% reduction in physician medication orders omitting site, route of administration, or dosage schedule, and a 32% reduction in radiology orders omitting clinical indications. In addition, they reduced departmental order turnaround times by 4.9 hours (71%) in the pharmacy and by 2.4 hours (9%) in the chemistry laboratory [1986[23]].

More recently, the experience at the University of Virginia (UVA) has confirmed the difficult course that POE follows, even with ultimate success. The UVA began installation in 1985 with basic administrative functions such as admission, discharge, and transfer. Beginning in 1988, radiology and dietary came on line. Mandatory POE for radiology, dietary, and laboratory followed, accompanied by result reporting. Pharmacy order entry followed in July 1989 and met with strong opposition from the housestaff. Dissatisfaction with the system peaked a year later, when a work action was initiated by a group of the most frustrated residents. During an open meeting with these physicians, senior members of the medical center administration stressed the system's strategic importance and reaffirmed their decision to keep it operational. Following this meeting, the work action was stopped and a few days later the new housestaff class arrived and was oriented to the system with little difficulty [1993[82]]. Ordering from the remaining ancillary services and nursing procedures was introduced in the final phase. The entire project took three years longer than planned and cost nearly three times the original estimate. The end result, however, has been good; housestaff now tell recruits that the POE system is one of the reasons to come to UVA.

Massaro stated that the UVA medical information system (MIS) did not truly begin to be integrated into the operational culture of the institution until after the Computer and Information Sciences Executive Committee was created and began to meet weekly to address these important changes [1993[81]]. This committee was composed of the chairs of medicine, surgery, and pediatrics, the executive director of the medical center, the director of nursing, the chief information officer, and the senior associate vice-president of the UVA Health Sciences Center. Perhaps the most important lesson learned at UVA is that information technology alone can not fix many problems the technology did not create, but the technology can accentuate existing problems by forcing strict adherence to seldom-followed rules and by diverting attention from the fundamental issues involved.

The HELP Clinical Information Management System

At the LDS Hospital in Salt Lake City, Gardner et al. [1990[50]] developed an on-line critiquing system for use by physicians and nurses when ordering blood products. Their system utilizes the HELP clinical information management system [1972[2]; 1983[15]; 1991[60]] to integrate patient data from eight different sources within the hospital: 1) blood bank, e.g., blood that is already ordered; 2) admit/discharge/transfer, e.g., patient demographics; 3) clinical laboratory, e.g., hematocrit and hemoglobin values from the complete blood count (CBC); 4) surgical schedule; 5) nurse charting, e.g., vital signs—heart rate, blood pressure, and fluid loss; 6) bedside monitors in the intensive care unit (ICU), e.g., blood pressure, O_2 saturation; 7) blood-gas laboratory, e.g., hemoglobin, O_2 saturation; and, 8) physicians' and nurses' data entry, e.g., current bleeding status plus reasons for overriding the system.

For the academic year 1988–89 there were 13,082 orders for 48,581 units of blood products (only 29,702 were actually issued) entered into the HELP system [1992[69]]. Physicians entered 42.7% of the orders directly from the terminals. Standing orders, which are automatically initiated from the computerized surgical schedule for 21 specific procedures (e.g., open-heart surgery or total hip replacement) accounted for another 8.1% of the total orders. The remainder of the orders were entered by nurses and consisted of 27.4% written orders (38 of the 405 physicians—9.4%—accounted for 66.6% of the written orders), 14.1% verbal orders, and 7.8% phone-in orders. The average time to place an order using the computer system was 2.2 minutes. Since the information from the clinical laboratory and previous blood orders were presented during the order-entry process, Gardner et al. concluded that the computer-based system was time- and cost-effective compared with the time spent searching the manual, paper-based chart for the latest laboratory results and previous blood orders.

Since their main goal in introducing the direct POE system for blood products was to improve compliance with Joint Commission on Accreditation of Healthcare Organizations (JCAHO) guidelines, Lepage et al. performed a quality-assurance review of all orders placed during the 1988–89 academic year [1992[69]]. Of the orders entered, 86.8% (81.3% of the actual units ordered) complied with criteria established by the medical staff (criteria were derived from the medical literature with slight modifications due to the altitude, 4,600 feet above sea level, of the LDS hospital). Of the 13.1% of the orders that initially appeared not to meet the established criteria, 27.5% (of the 13.1%) occurred because "no reason" was specified in the order (3.6% of the total). Nurses were specifically instructed not to "guess" at reasons for order exceptions (i.e., those not meeting the established criteria based on data already in the database) on written or verbal orders without specific reasons stated. After careful review of the remainder of the orders not meeting established criteria, the quality assurance department found that only 48 (0.37% of the total number of orders) were true exceptions to the established criteria for utilization of blood products.

Regenstrief Medical Center

Investigators at the Wishard Memorial Hospital began using the Regenstrief Medical Record System in 1973 [1976[5]]. Since 1984, they have developed successive components of a POE system [1986[25]]. An innovative aspect of their work was the inclusion of CARE rules (patient-specific medical reminders based on algebraic combinations of raw data and/or other CARE rules), which are executed automatically when triggered by data or order entry for the associated test or treatment [1981[12]]. In addition, McDonald and colleagues have also developed a "medical gopher," which assists in the performance of many routine clinical activities by reducing the work of locating pertinent general medical information. For example, when a physician orders treatment for a specific problem, the medical gopher displays the most common workup and/or treatment for the problem. Displayed items can then be ordered using one or more menu selections. Drug–drug, drug–test, and drug–diagnosis interactions are also detected automatically and a warning message is displayed before the order is completed.

In the early implementation phase of the POE system, all data entry was accomplished via keyboard. Using this early technology (80286s and keyboards) McDonald and Tierney found average order times of 30 seconds/test [1986[25]]. They subsequently upgraded their PCs to 80386s and added mouse-based data entry, although they still report that physicians prefer the keyboard data entry over the mouse in a ratio of ten to one [1991[62]]. Since the system includes data display for decision support in the order process, computer-based POE still requires more time than the manual system (58.5 vs 25.5 minutes during a ten-hour period, $p < 0.0001$) [1993[84]]. Of greater importance is that they were able to reduce inpatient charges and estimated hospital costs significantly [1993[84]]. In a subjective evaluation conducted by Tierney et al., 70% of the responding clinicians felt that using POE made their work more interesting, and 44% felt that their work was done faster using the system. Interestingly, 52% said that the POE made their work easier [1993[84]].

Rationale for Direct POE

Physician order entry is a strategic option for facilities considering how to deal with the twin requirements of health reform—improvement and documentation of quality while containing cost [1993[76]]. Although it is easy to understand the importance of POE from the perspective of organizational leadership, it is harder to rationalize from the perspective of the individual worker. For POE to be successful, project leaders must carefully consider the work patterns of individuals. POE systems must deliver tangible benefits to users if the change is to be made without creating a net disadvantage for any key group.

Benefits that can accrue from implementation of POE can be categorized as follows: process improvement, cost-conscious decision making, clinical decision support, and optimal use of physician time. Process improvement involves the re-engineering of the entire order-entry process so that those responsible for the decisions are directly involved in the entering of orders. This improves the conveyance of orders as well as enabling the system to provide real-time feedback to clinicians regarding the appropriateness of certain orders [1993[76]]. Cost-conscious decision making involves presenting clinicians with less expensive tests and/or treatments for a specific diagnosis, or presenting the cost of each test or treatment to the clinician at the time it is ordered [1990[56]; 1993[84]]. Clinical decision support involves providing information relevant to formulation of a diagnostic hypothesis or appropriate therapy. Benefits of one type often cause gains in the other areas. For example, process improvement also decreases fragmentation of the health professional's time.

Process Improvement

The process improvements identified below save the ordering physician time by decreasing the need to repeat tests or procedures whose results are lost, or actions that have not been carried to completion. They improve the timeliness and reduce the cost of care.

Process improvement via POE:

- Can eliminate lost orders, since the initial record of an order is made directly into a computer database. Thus, follow-up on overdue orders can be automated.
- Can virtually eliminate ambiguities caused by illegibility of handwritten orders (orders typed in freetext can still be potentially misunderstood). Incomplete orders are not possible. At the Kochi Medical School Hospital in Japan, inquiries from pharmacists to the ordering physicians after a prescription audit of handwritten prescriptions amounted to 11% of orders [1988[36]]. Following implementation of the hospital's computer-based order system this percentage dropped to 1.4% (approximately one every four hours).
- Can generate related orders automatically; for example, a heparin-flush order could be generated with every nursing order to establish an indwelling intermittent injection site.

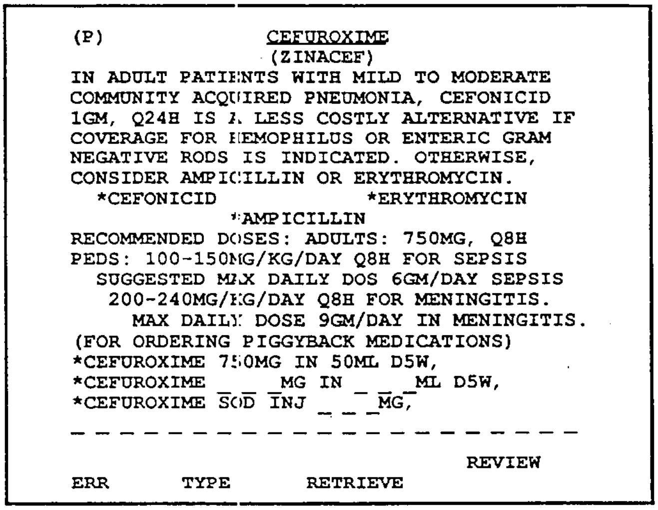
- Can generate automatic stop orders for prophylactic antibiotics [1990[49]].
- Can continuously monitor all orders for a particular patient and prompt the clinical staff regarding whether an order is a duplicate [1985[19]].
- Can reduce the time required to fill drug orders. For example, in a randomized controlled clinical trial, Tierney et al. were able to show that admitting drug orders were filled 63 minutes faster on average, while daily drug orders were filled 34 minutes sooner [1993[84]].
- Can integrate quality-assurance monitors into the order-capture process [1990[50]]. For example, at the LDS Hospital in Salt Lake City, all physicians are required to provide reasons for ordering blood products if the database (laboratory results, operative schedule, etc.) does not contain justification based upon established criteria.
- Can reduce the amount of money hospitals spend on preprinted multi-part forms used in the order-entry process. Hodge estimates that savings of $5,000 per month or more are not unusual [1990[52]].

Support of Cost-conscious Decisions

Support of cost-conscious decision making involves increasing the awareness of the cost of a service so that it is avoided entirely when not needed or by identification of less expensive alternatives.

Cost-conscious decision making through POE:

- Can assist in keeping prescribing practices consistent with a hospital's established formulary, resulting in significant cost savings [1986[26]].
- Can educate physicians regarding cost-effective medication options. For example, Reynolds et al. found that presenting educational comparative therapeutic and cost data for clindamycin, cefoxitin, and metronidazole resulted in a 400% increase in the use of metronidazole with a concomitant decrease in clindamycin usage ($p < 0.001$) [1988[37]]. Kawahara et al. showed that the percentage of patients with community-acquired pneumonia due to *Haemophilus influenzae* or gram-negative enteric rods who were prescribed cefuroxime decreased from 100% to 22% over a one-year period (the average cost of antibiotics per patient decreased from $123 to $48) [1989[43]] [see Figure 1].



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(P)                 CEFUROXIME
                     (ZINACEF)
IN ADULT PATIENTS WITH MILD TO MODERATE
COMMUNITY ACQUIRED PNEUMONIA, CEFONICID
1GM, Q24H IS A LESS COSTLY ALTERNATIVE IF
COVERAGE FOR HEMOPHILUS OR ENTERIC GRAM
NEGATIVE RODS IS INDICATED. OTHERWISE,
CONSIDER AMPICILLIN OR ERYTHROMYCIN.
  *CEFONICID               *ERYTHROMYCIN
            *AMPICILLIN
RECOMMENDED DOSES: ADULTS: 750MG, Q8H
PEDS: 100-150MG/KG/DAY Q8H FOR SEPSIS
  SUGGESTED MAX DAILY DOS 6GM/DAY SEPSIS
   200-240MG/KG/DAY Q8H FOR MENINGITIS.
     MAX DAILY DOSE 9GM/DAY IN MENINGITIS.
(FOR ORDERING PIGGYBACK MEDICATIONS)
*CEFUROXIME 750MG IN 50ML D5W,
*CEFUROXIME _ _ _MG IN _ _ _ML D5W,
*CEFUROXIME SOD INJ _ _ _MG,
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Figure 1 The cefuroxime order-entry screen. Notice that the physician can select the cefonicid alternative directly from this screen without returning to the alphabetical index of medications. Selection of the cefonicid alternative will take the physician directly to the cefonicid dosage selection screen. This saves the physician several steps in the order-entry process. (Adapted from Kawahara.[43])

- Can prompt the ordering physician regarding optimal routes of medication administration, e.g., if a patient is taking pills orally, and a new medication that exists in equally effective oral form is ordered to be given IV, then the system could provide the information that the oral form is available and costs significantly less [1983[14]].
- Can inform physicians of test charges before completion of the order. Tierney et al. showed that both the number and the cost of tests ordered by resident physicians could be reduced significantly by this simple action [1990[56]].
- Can reduce the number of tests ordered by presenting previous test results to clinicians before they order new tests. Specifically, Tierney et al. were able to demonstrate that resident physicians who were automatically shown past test results ordered 8.5% fewer tests, resulting in 13% lower charges as compared with physicians not shown such results automatically [1987[30]]. The same study documented that displaying the previous test results added only 4.5 seconds (8%) to the entire order-entry process.
- Can reduce laboratory costs by presenting physicians with predictions of test abnormalities, based on predictive equations (derived from retrospective patient data) calculated using current patient-specific data in the system. One hospital was able

to reduce the number of tests ordered as well as the cost of clinical laboratory testing by 8.8% ($p < 0.05$). Reductions of more than 10% for the most commonly ordered tests (electrolyte levels and complete blood cell counts) were attributed to this technique [1988[39]].

Clinical Decision Support

Many investigators argue that the greatest long-term benefit of POE will come from the integration of clinical decision support into the order-entry process. Clinical decision support requires a current and accurate knowledge base. The difficulties in developing and maintaining such a resource are significant [1992[66]]. Clinical decision support can be applied at several different levels of complexity.

For example:

- The system can also make available to the clinician relevant information such as on-line laboratory manuals, the *Physician's Desk Reference*, a textbook of medicine, or even the entire Medline database [1986[25]].
- Informational text can be inserted into the order-entry pathway, providing accessible and consistent information when the therapeutic decision is being made. This can reinforce guidelines (e.g, maximum potassium concentration that can be infused by a peripheral intravenous route). In addition, POE can be an effective method for rapidly disseminating drug-recall information [1986[26]].
- The system can automatically make complex calculations for drug dosage and/or parenteral and enteral feedings, based on patient age, sex, weight, and other clinical information [1989[45]; 1992[68]]. The system can check whether the dose, duration, and frequency of administration are within hospital guidelines [1985[19]]. For ethical, clinical, and medicolegal reasons it is probably best if these calculations are used in a "open-loop" environment in which a physician always has the final decision.
- The system can generate reminders at the time a physician enters the order. Reminders can assist with: 1) interactions among concurrent drugs that may have been ordered by multiple practitioners (drug–drug interactions), 2) potential interactions between laboratory tests and specific drugs (i.e., a laboratory test whose results will not be meaningful because a particular drug has been given), 3) drug orders that should be modified based on laboratory values [1991[58]], 4) potential allergies [1988[36]], or 5) potentially toxic conditions requiring attention (e.g., high drug levels in laboratory results, or the order of overdosage, or the order of interacting drugs that increase levels) [1984[16]].
- The system can automatically suggest certain therapeutic orders for review by a physician before they become active, based on clinical data available within the system [1989[47]; 1992[70]].

Optimization of Physician Time

The physician gains satisfaction and competitiveness through the process-improvement and decision-support aspects of POE. Correctly implemented, POE should pay back the physician directly through time savings.

- Physicians can place orders from any location in the hospital (and some hospitals allow physicians to log-in from their homes or offices) and be confident that they will be carried out in a timely and appropriate manner [1993[83]].
- The number of telephone calls inquiring about orders can be greatly reduced [1986[20]; 1988[35]].
- Order sets can reduce the need for physicians to memorize and regurgitate routine orders, thus freeing them to concentrate on identifying the unique features of a patient's illness and then tailoring the care plan to reflect those differences. Indiscriminate use of order sets can result in unnecessary orders.

Sociologic Barriers to Direct POE

Physician order entry is consistent with the industrial adage that data capture and data use should occur directly at the point of service. Achieving POE is difficult because in the health care system the most highly trained and compensated personnel (i.e., physicians and nurses) are at the point of service, unlike other industries that have lower skilled and less costly personnel in those positions [1993[81]]. This difference leads to a common perception that the purpose of POE is to save money for the hospital by shifting work from clerks to physicians [1980[11]]. The hospital must be willing to invest money to give the physicians a better method for writing orders.

The goals of POE are to capture a non-ambiguous order at the source, to permit integration of decision support into order generation, and to act on orders in a more timely fashion. The institution must communicate clearly the strategic importance of POE and work with the physicians and other care providers to develop an approach that they see as helping them as individuals. If this communication is not put in place early, distrust and fear will build into powerful barriers to implementation [1993[81]].

Another related fear is that POE will de-intellectualize the practice of medicine by making physicians use protocols. Instead, POE can decrease the amount of time that physicians spend on routine aspects of care, allowing them to focus their attention upon the unique aspects of a case. In addition, development of a clinically defensible order set, based on data about variations in practice patterns or the results of clinical trials, can be an educational experience for attending physicians and students alike [1992[71]].

Changing Practice Patterns

Hospital information system (HIS) developers commonly build order-entry pathways, or menus, for clerical use. Such system developers obtain input from the ancillary departments rather than from physicians [1982[13]]. With a paper order sheet, when a physician writes an order in conflict with the hospital's or a department's rules, a clerk may buffer the physician from the problem by modifying the order during the data-entry process. Otherwise the department will later call the physician to resolve the problem. The clerk learns individual physician preferences over time, often through repeated criticism when things go wrong. If the physician changes patient care units, or a key staff member leaves, the protective buffer provided by the clerk must be redeveloped. With POE, there is no buffer between the physician and the institution's rules/procedures. The developers and phyisician users must put energy into training the computer system so that a "human buffer" is not necessary. This investment must be repeated if the POE system undergoes major redesign.

Physician order entry forces physicians to modify established practice routines and work-flow patterns. POE is best introduced by including physicians in the entire decision-making process. In hospitals with house officers, it is difficult to involve the interns (one year postgraduate MDs), who will be the main users of a POE system, in the developmental decision-making process. Interns have very little free time to begin with. While residents (two-to-four-year postgraduate MDs) may have more time, the POE selection and implementation process may be longer than the remainder of their residency program. The residents who have been involved in the decisions will not be around when the system is finally put into use. Subsequent generations of residents may perceive that they were not consulted in the selection process, and hence want nothing to do with the system [1992[65]]. On the other hand, residents who come to the hospital after POE has been implemented may perceive the system as the status quo and raise very few objections. In several instances, a POE system has become a "strategic advantage" in recruiting new residents.

In an attempt to minimize the disruptions to the traditional order-entry procedure during the implementation of POE, the Albany Medical Center offered a transcription service (to enter orders into the system for the physician) from 10:00 AM to 6:00 PM. In a review of one month's activities, 73% of the orders (4,836 total orders) were entered by the physicians themselves (an additional 9% were verbal orders entered by the nursing staff). Developers attributed the limited usage of the transcription service (18% of all orders entered) to problems with the transcriptionist. Specifically, they mentioned problems with reading physicians' handwriting, delays in entering the orders, and the fact that someone was still expected to verify the data entered. Many of these problems were the same problems that POE was designed to address [1990[55]].

Massaro, in an attempt to alleviate the perceived POE-related increase in clerical work required of the housestaff, used a fax machine to send handwritten orders to the pharmacy on three separate patient care units [1993[82]]. Intially 22% of the orders were captured in this manner. After three months of operation, as problems with the POE system were resolved and the users gained experience entering orders, use of the fax dropped to 2 to 3%. Subsequently, the fax machine was eliminated. Others have commented that use of the fax machine to send physicians' orders to the pharmacy does not address many vital issues [1989[40]; 1989[44]].

Shifting Roles within the Care Team

Physician order entry allows order entry to take place from anywhere within the institution and possibly from home. Accordingly, POE should decrease the need for verbal orders. Indeed, care must be taken to keep verbal orders from becoming a way of avoiding use of the POE system. At the same time, policy should permit verbal orders when they make sense. For example, if a physician is called during the night and told that "a patient can not keep down his Compazine," the physician should be able to ask the caller to change the administration route to rectal from oral (without having to log into a system). Nurses might view entry of verbal orders as clerical work for the physician and refuse. Achieving the correct balance will require thoughtful discussion between members of the care team.

Changes in Traditional Teaching Patterns

Physician order entry will change the way people learn. In the past, clinical clerks (students) have learned by repetitively writing orders. Order sets, which can be part and parcel of efficient POE, eliminate this approach. On the other hand, ready access to information such as decision trees or clinical simulations during the order-entry process should provide new and better ways of teaching students and trainees.

Physician order entry can alter the manner in which students write orders. Orders from students ordinarily need to be discussed and cosigned by a resident. At the University of Virginia, residents found that it consumed more time to correct computer-based orders input by medical students than to input correct orders themselves. Therefore, the medical students received less of the resident's time and teaching [1993[81]]. On the other hand, Tierney et al. found that medical students value the "educational extras" available on the Regenstrief POE system. Students felt more at ease writing orders using the Regenstrief POE than using paper because it allowed them to write orders without "defacing" the chart and/or making their mistakes permanent [1994[86]].

A concern has been raised about what will happen when the physician who has been trained using POE leaves and goes to another institution [1992[73]]. First, all learning is site-specific to some extent. This problem has not been dealt with in any systematic manner to date. Second, if information technology is used to teach physicians how to make decisions about what to do, they may be able to pick up new routines more rapidly. Third, information technology is becoming ubiquitous. Digital information resources such as Medline [1990[51]], COACH [1993[79]], DxPlain [1987[27]], and QMR [1986[24]] are becoming available to practitioners, however, remote, via personal computers or telephone.

Inadequate Institutional Policies

Implementation of POE can force strict and literal interpretation of the policies, rules, and procedures of a medical center. This can cause frustration to users [1990[55]]. Policy problems may not be created by a new computer system; they most often will be brought to light by it. Policies and rules in place may not be followed rigorously. Implementation of POE can not proceed until procedural conflicts are resolved. Therefore, resolution of these problems must be handled rapidly and effectively at the highest levels within the organization (e.g., in an academic medical center by the dean, the director of the hospital, and the chief information office, or in a private group practice by the partners), an approach most organizations are not used to handling.

Logistical Challenges Involved in POE Implementation

The logistical challenges surrounding POE implementation often significantly outweigh the technologic challenges. Logistical problems include how to phase each step of implementation; training issues; the number of terminals required; and the time required to enter and review data. The hospital must commit sufficient capital, system personnel, and support personnel to achieve the transition. The physicians must commit their time and adapt their practices somewhat if the organization is to achieve better order generation and management.

Implementation Phasing

Phasing the stages of POE implementation is one of the most difficult aspects of installing a new POE system [1992[65]]. Possibilities include:

1. Implement all functions at all locations at one time throughout the hospital.
2. Implement all functions at one location. When that location has stabilized, begin rolling out the system to the remaining locations, one at a time.
3. Implement limited functionality at all locations, e.g., laboratory test ordering. As these functions are accepted into the normal clinical routine, begin to roll out more functions.
4. Combinations of these approaches, such as implementing limited functionality at one location are possible. When that functionality has stabilized, one can begin rolling out more functions at that location, and then roll out to other locations throughout the hospital.

There are many problems with implementing a system in stages, or in one portion of the medical center and not others. Problems include: 1) handling patient transfers from a "computerized" unit to a paper-based unit; 2) movement of clinicians between units on which the system is used and ones on which it is not; 3) dealing with two types of order processing in ancillary departments; and 4) how to convert the paper record to the computer-based system and vice versa as the patient is moved. The transition period can be traumatic to personnel and can generate unpredictable crises and costs [1992[72]].

McDonald [1991[62]] states that introducing POE in an outpatient clinic is easier than attempting the same feat on an inpatient ward. He found that for inpatients, the number of orders written and their variety were two orders of magnitude greater than in the outpatient clinic. In addition, telephone orders, student orders (which must be cosigned), and negotiable transfer orders that take effect if the bed is needed by a sicker patient add complicating wrinkles to the inpatient order-entry problem. Moreover, the turnover rate at McDonald's institution was higher (nearly 50 new physician/medical student users every six weeks) in the inpatient setting, which resulted in higher training costs since the entire hospital was not using the system [1991[62]].

Schroeder [1986[26]] described a successful transition period in which no more than one patient care unit was brought on line at a time. During the year-long implementation phase, they added an average of one new unit on line every two weeks. Specially trained pharmacy technicians were available 24 hours per day for the first three to four days, and waited unobtusively until signs of frustration became apparent. They were instructed to offer their assistance at that point. In this way, the number of truly negative experiences was greatly reduced.

Number of Terminals and Location

Ideally, a workstation would be available wherever a physician might enter an order, however, the high-powered workstations are too expensive to place wherever they might be needed. Therefore, POE currently requires use of a pool of shared workstations distributed around the patient care unit. Many institutions using POE have between three and five terminals per nursing station or approximately one terminal for every five to ten patients (depending, in part, upon patient acuity [1986[26]; 1993[84]; 1993[81]].

The number and location of workstations must be selected to minimize the number of times that physicians have to wait for a terminal and the distance that they have to walk. Even so, physicians may help by staggering rounding patterns where possible and by using clipboards to note orders prior to subsequent entry. In the future, hand-held tablets that communicate back to host databases over wireless networks may allow physicians to enter orders from anywhere within the hospital. However, the press for better user interfaces has resulted in order-entry systems that require more computer power than can be managed today with a truly hand-held device.

Training Users

Installing a POE system requires massive training efforts. One must factor in not only the cost of the training staff but also the cost of adding additional workers to maintain hospital functions while the regular staff is being trained. Several training models and/or methods have been tried, including:

1. Either offer a comprehensive course as an entire-day session or offer multiple one-to-2-hour sessions.
2. Offer a short course to cover the absolute minimum amount of functionality and then have specially trained staff available to help physicians learn the remainder of the functions as they care for patients on the wards.
3. Develop a self-paced, computer-based training module that the physicians can complete at their leisure.

At the University of Virginia, over 3,600 nurses, 1,200 residents, 800 medical students, and 200 attending physicians were trained to use an order-entry system [1993[81]]. Physicians were trained in a six-hour course. Physicians could take the entire course at once or in six one-hour segments at their convenience. It is not uncommon for individual sign-on codes to be withheld until physicians have completed the training course [1986[26]]. It is a common perception that effective physician training requires two to six hours of one-on-one training, which is best accomplished, or tolerated, if presented by another member of the medical staff [1992[65]].

Community Memorial Hospital in Toms River, NJ, selected a group of nurses (12) to provide training for all physicians (200) [1988[35]]. The trainers were responsible for developing orientation packets and for scheduling training sessions. All training was done in one-on-one sessions lasting two hours. During implementation, trainers were available at all nursing units. In addition, demonstrations of the information system were held monthly for physicians.

Training is important, not just to make sure that orders are entered correctly, but also to help physicians learn to be efficient. Ogura et al. compared two groups of physicians selected by their amounts of computer training. They found that the more experienced physicians entered orders approximately 30% faster (60 sec vs 86 sec) [1985[18]].

Many investigators have reported that while initially POE requires more time to learn than the paper method, over a short period (2 weeks to 2 months), there is no significant difference between paper-based and computer-based order entry times [1980[10]; 1986[22]]. Specifically, Schroeder states that "after one or two weeks of use, most physicians find they can enter orders in the computer terminals faster than they could write them by hand" [1986[26]]. One must be careful when assessing these numbers, since systems are often customized to meet various requirements of particular institutions. Times to enter orders and times required to learn to use the systems may vary greatly.

Time Required to Enter Orders

In an 11-day study in Japan, investigators found that 5,562 prescription orders (2,952 new and 2,160 repeat orders), 4,363 laboratory orders (3,820 entered by physicians), and 1,218 X-ray orders (1,217 entered by physicians) were input to the system [1985[18]]. During the study period, the mean time to enter a new prescription was 102 seconds (SD = 121 sec) while a laboratory order required 76 seconds (SD = 109 sec), and a radiologic examination 54 seconds (SD = 82 sec). They made no timing comparisons with the previous paper-based system.

In a formal time–motion analysis of the effect of using POE, Tierney et al. found that physicians spent an average of 33 minutes more writing orders between the hours of 10 AM and 8 PM than did controls using a paper-based system (58.5 vs 25.5 min, $p < 0.001$) [1993[84]]. This averages out to 5.5 minutes longer per patient writing orders during the study hours. Much of this difference (9.9 of 33 min) can be accounted for by the discharge order process. Control physicians simply wrote "discharge patient today," whereas the intervention group had to include prescriptions, discharge planning information, and a brief typed discharge summary. In other words, they took longer but they did things that the manual group would have to do outside the order-entry process. A portion of this increase in time was recaptured by the intervention group through a 5.7-minute savings in the time spent managing "scut" cards (short notes that record vital patient information).

In an analysis of the time spent by residents (all services combined) using POE, Massaro found that less than 10% of the residents spent over 60 minutes during a 24-hour period on the computer, although on specific high-volume rotations and/or services it was not uncommon for residents to spend four to six hours at the terminal in a 24-hour period [1993[81]]. He also found that first-year residents (who enter the majority of the orders in any system) spent significantly more time at the computer than did the more experienced residents. At Yale–New Haven Hospital, Clyman reported that "a surgery intern entered 475 new orders into the computer in one day" and that "only 50 of these originated from order sets" (J. Clyman, 1993: personal communication). These patterns suggest that one person is being assigned the duty of entering orders for a large team. Orders should be entered by the decision maker wherever possible if POE is to deliver its full potential benefits.

System Design Issues

Capabilities/Policies Required by POE

POE requires features beyond those found in a system designed for clerical users. In most cases, additional policies and system functions must be created for an integrated, efficient system, including:

Electronic Signatures. One must be sure that electronic signatures are legal and binding in the state [1992[72]].

Suspended Orders. A mechanism should be in place to allow pre-admission orders to be entered for patients before they arrive at the hospital. The orders must remain suspended until the patient is admitted and then automatically activated. A similar mechanism could permit suspension of orders on transfer, with selective reactivation and countersignature by the receiving physician.

Countersignature Orders. Two types of countersignatures must be supported. The first is legal countersignature of a verbal order. In this case, the order can be activated prior to countersignature but the nurse recording the order must have an electronic signature and must indicate which physician generated the order. The second is countersignature of an order (by a medical student or nonauthorized consultant) that had to be held pending countersignature [1993[83]].

Order Modifications by Medical Students. When an active order is modified, the order is actually discontinued and a new order is initiated. Provision must be made to hold both actions for countersignature.

Consultant Orders. A method must be in place to allow consultants to enter orders. Questions arise regarding whether or not these orders should be acted upon without permission from the attending physician.

Downtime Procedures. During system downtime, orders are written on a paper order sheet. Who enters these orders once the system comes up if clerks are not used to handling orders? Do physicians need to countersign orders that have been entered into the system by clerks based on those that they have already written out by hand? Another question that must be answered is: How are orders that were in the system retrieved and processed once the system goes down?

Data-entry Methods

Experienced users achieve speeds of up to 15 keystrokes/second (approximately 150 words per minute) on the keyboard, but beginners struggle along at less than one keystroke per second [1987[29]]. Many different hardware modalities have been tried to facilitate data entry, including the light pen [1988[33]], the mouse [1986[25]], the trackball [1993[74]], the touchscreen [1990[55]], voice recognition [1991[59]], bar codes [1993[77]], special-purpose (book style) keyboards [1980[11]], and more recently, the gesture-recognition systems of the pen-based operating systems [1993[80]]. Successful systems usually employ one of these modalities in conjunction with the keyboard.

Childs [1988[33]] found that light-pen technology along with user-friendly menus allowed users of the TDS system to perform all of their functions with less than 1% typing. Others have experimented, albeit unsuccessfully, with popping up alpha-numeric keypads on the screen and allowing users to pick off the numbers or letters that they wish to enter with a mouse [1991[62]]. These indirect pointing devices require much more cognitive processing and hand–eye coordination to bring the on-screen cursor to the desired target [1987[29]].

Outpatient Prescription-writing Systems

Outpatient prescription writing is the area in which the most work has been done regarding tailoring of a user interface for POE. Reported average times to generate prescriptions using computer-based POE range from 4.2 minutes for complex prescriptions to under 30 seconds for the simplest (similar times were found using paper-based systems) [1986[22]; 1986[21]]. The outpatient setting lends itself to POE evaluations because only a small number of physicians need to be involved. Prescriptions are a good test case because they represent a large volume of potentially complex orders.

Levit developed a system to capture prescriptions entered in coded form [1977[6]]. Most drug codes utilized the first two letters of the drug name. Following the name of the drug, the physician entered the dosage form. Common abbreviations included T for tablets or capsules, S for solutions, and C for creams, etc. Following the dosage form the unit dose amount was entered. Most of the doses used the first significant digit of the number (e.g., 2 for 250 mg). The physician then entered the code for the number of capsules of the total amount of the drug to be given. Once again, only the first digit of the total amount of the dosage was entered as the code. Thus, to write a simple prescription for 60 250-mg tablets of tetracycline, one would enter TET26. If the code stopped at that point, the directions "Take as directed" would also appear on the label. It was preferable, as well as possible, to enter codes for "how many" and "how often" as well. Once again, one entered the first digit for "how many" and the first letter of the commonly used Latin abbreviations for "how often" (e.g., 2T for two tablets three times per day—t.i.d.). Defaults for the number of refills could be set or the number allowed could be entered as R followed by the number of refills allowed. More complex codes were also possible by including text between asterisks and/or combining instructions with a plus sign. This approach was efficient for the expert user, but it is probably not applicable to large physician populations at a medical center because of the extensive training requirements.

Brown et al. developed another innovative user interface to a prescription-writing system that requires only five function keys (the arrow keys) to generate a complete detailed prescription [1985[17]]. In addition, medication names are accessed rapidly from a doctor's personalized drug formulary, which is indexed by conventional therapeutic groups and cross-indexed by disease or diagnosis groupings. Finally, extensive use is made of defaults, which allows the physician to order by defaults and exceptions. To order a drug the physician presses and holds (keys are automatically repeating) an arrow key that causes a simulated wheel to rotate on the screen. When the appropriate dose form or timing, or both, is visible, another key is pressed to select that item. They compared order entry times of novices with those of an experienced user and found that the experienced user required 18 seconds on average to complete the orders while the novice users required 82 seconds [1986[20]]. The system has been in continuous operation for over three years.

Order Sets

Order sets allow users to issue prepackaged groups of orders applicable to a specific diagnosis or to a specific time period within an episode of care (e.g., admission or postoperative orders). Order sets can reduce the task and error rate of writing common repetitive orders. Anderson et al. [1988[31]] developed a computer-based simulation to represent the process through which physicians and other hospital personnel enter orders into a hospital information system. They found that by increasing the use of order sets by approximately 50% that they could reduce the time hospital personnel spent entering orders by 20% and decrease terminal usage by 30%. They be-

Table 1 ■

Some Benefits of Order Sets*

Category	Benefit
Quality	Reduction in transcription errors
Quality	Promotion of adherence to consistent standards of care
Quality	Focus attention upon unique features of a patient
Productivity	Quicker order entry
Productivity	Reduction in delays due to inconsistent or incomplete orders

*Modified from Levine.[61]

lieve that they could decrease the percentage of undetected errors in orders by 40% using this technique. Order sets allow clinicians to determine appropriate orders away from the time and emotional pressures of the day-to-day clinical setting [1990[54]].

Order sets are usually developed by a group of physicians with a common clinical focus. The process involves a review of current clinical practices followed by development of consensus regarding the best diagnostic and treatment options. Another approach is to "memorize" sets (i.e., save them as a byproduct of normal order entry and then recall at a later date) during routine order entry. These so-called personal order sets (POSs) have high physician acceptance. Drawbacks to these POSs include the fact that they may reinforce inefficient medical care. In addition, the number of POSs may become unmanageable. For example, at the University of Virginia, a resident-led oversight committee was required to reduce the number of POSs generated by 273 residents in the first two years of operation from 2,684 to 545 (or from approximately 10 per resident to 2 per resident) to improve maintainability of the system [1993[82]]. Maintainability becomes a significant problem if either the laboratory or the pharmacy changes a specific test or treatment that is included within multiple order sets. In this case, someone must change every order set or clinicians will have to correct that specific order every time one of the "incorrect" order sets is selected.

Levine et al. state that the benefits associated with order sets can be grouped into two main categories: those that improve the quality of medical care and those that enhance workers' productivity (see Table 1) [1991[61]]. While many clinicians and administrators are strong supporters of the development and use of order sets, others argue that their potential drawbacks limit their utility in many situations. Specifically, there are concerns that order sets lead to the practice of "cookbook" medicine. If developed or used indiscriminately, order sets may increase unnecessary orders. Opponents also argue that the use of order sets adversely affects the educational process since students do not get the experience of repetitively writing out common orders.

Many types of order sets have been used. The first category lists common orders for a department, service, or patient unit on a menu for rapid selection. Orders are selected from the menus and completed individually. The second category lists detailed orders for a procedure or day of care. Orders are selected as a group with minor editing by exception to reflect patient variations. A third category outlines order options with multiple-choice or fill-in-the-blank fields. These order outlines are a compromise between individual orders, which require many individual steps to complete, and order sets, which have very little flexibility. A fourth category of order set differs from the first three categories in that it is created on the fly by an algorithm in the clinical information management system that takes into account pertinent clinical data. In the simplest sense, this type of order set may consist of a rank-ordered list of common options [1986[25]]. In its most complex sense, the system may suggest a specific order for a particular patient automatically [1989[47]].

In an attempt to improve the acceptance of order sets in general, Anderson et al. conducted a study at Methodist Hospital of Indiana, a large private teaching hospital, to see if they could increase the use of order sets [1988[32]]. Their intervention consisted of individual meetings with the physicians identified as being educationally influential. At these meetings, members of the HIS project staff discussed current usage statistics of the HIS in general and order-entry statistics in particular with emphasis on the advantages of using order sets. They compared the use of order sets before and after initiation of their intervention. They showed a significant increase in the use of order sets by the physicians in the group headed by the influential physicians over the control group. They concluded that use of these influential physicians was an effective method of changing physicians' practice patterns with respect to the use of order sets.

Use of Expert Systems to Facilitate POE

One of the primary justifications of POE is that computer-generated reminders and/or advice can be provided to the person best able to act on the information at the time and place that the action is required [1989[41]; 1991[63]]. Many of these "expert systems" have been developed, but few have been integrated into the normal ordering routine. The following examples illustrate how such systems can work.

Systems to Facilitate Ordering of Radiologic Procedures

The PHOENIX expert system [1987[28]; 1989[42]] is integrated with the Missouri Automated Radiology System (MARS) computer system, a dedicated radiology information management system [1973[3]] at the University of Chicago Medical Center. The prototype system contains information for ten common procedures (e.g., chest, abdomen, and cervical spine radiography, abdominal computed tomography, gallbladder sonography). PHOENIX can assist the ordering physician by providing reminders, such as asking whether females between the ages of 6 and 60 might be pregnant, before completing the order for a usual two-view chest radiograph. PHOENIX reminds the physician that it may be inappropriate to perform a contrast-enhanced CT on a patient with an elevated serum creatinine level unless certain conditions are met (e.g., dialysis is provided following the procedure). In addition, PHOENIX will interview the ordering physician to help determine whether a screening mammogram (appropriate for an asymptomatic woman with no prior breast abnormality), or a dedicated mammogram, which requires physician supervision and possible additional views, is indicated.

DxCON, developed by researchers at Yale University as a prototype artificial intelligence-based computer system, gives advice to physicians regarding the optimum sequencing of radiologic tests for diagnosis of obstructive jaundice [1989[48]]. DxCON utilizes the critiquing mode of interaction in which the computer does not tell the physician what to do, but rather asks the physician about the patient and the intended workup plan and then discusses the strengths and weaknesses of that plan in an English-prose discussion that is tailored to the physician's specific plan. In this way, the physician can evaluate the appropriateness of the computer's conclusions and advice regarding a specific patient. In several example cases, DxCON has produced convincing critiques of several different work-up plans [1989[48]].

Systems to Facilitate Transfusion Orders

Using *HELP*, Lepage et al. developed a consultation module that recommended the type of blood product (red blood cells or platelets), authorized the number of units to be ordered, and suggested an ordering priority [1992[70]]. In a three-month retrospective study, they found that the computer-based blood-ordering consultant accurately recommended 95.5% of the orders (for which data were available in the computer) that were entered. They also evaluated the quantities of blood products ordered and found agreement in 71.2% of the cases. In the remainder of the cases, the computer recommended smaller numbers. Lepage et al. concluded that their consultation system could simplify the blood-ordering process and reduce the number of units ordered. A clinical trial comparing the critiquing mode with the consultation mode is planned.

ESPRE, a knowledge-based expert system developed at the University of Minnesota Hospital and Clinic, provides automated decision support for blood bank personnel in assessing requests for platelets [1989[46]]. ESPRE uses a hybrid rule-based and frame-based knowledge-base structure to provide information about diagnoses and conditions such as disseminated intravascular coagulation, prolonged coagulation time, poor platelet activation, infections, and surgical procedures that affect transfusion requests. In a random sample of 75 platelet transfusion requests, ESPRE's recommendations agreed with those of blood bank 93% of the time [1989[46]].

In a similar vein, Spackman et al. [1988[38]] developed the *Transfusion Advisor (TA)*, which critiques the appropriateness of orders for cryoprecipitate, frozen plasma, and platelets. In a review of 31 consecutive requests for these blood products, there was total agreement between the TA and the medical director of the blood bank in favor of carrying out the order in nine cases. In an additional 19 cases, both the medical director and the TA decided that transfusions were not required. In three cases, the TA's knowledge base was found to be deficient and promptly fixed. The authors noted that if the TA had been responsible for dispensing the blood products that were ordered in these 31 cases, the hospital could have saved over $2,200 (60% reduction).

Implications for Future POE Systems

Past experience suggests the following key ingredients for successful implementation of POE. First, the system must be fast (sub-second response time) and must be easy to use with a minimum of training. In the event that assistance is required, it should be available 24 hours a day both on line and by telephone. Consistency of the system interface and behavior may be more important than having different screens and/or responses tailored to specific situations. Second, broad and committed involvement and direction by physicians prior to implementation is vital. POE must have real and committed sponsorship within the clinical community. Third, the top leadership of the organization must be committed to stay the course of implementation. Problems will occur; they will be solved only if people focus upon how to make the system work better instead of being diverted by the question of whether the institution should be implementing POE. Finally, a group of problem solvers must meet regularly with users to work out procedural issues that cross boundaries. The group must include someone from each of the following areas: attending physicians, housestaff, nursing, admitting, laboratory, pharmacy, radiology, billing, and information management. The group must contain individuals who are empowered to commit to specific decisions that require changes in the areas they represent. The goal should be to discuss a problem and agree on a solution one week and to implement that solution prior to the next week's meeting.

Optimistic forecasts must be balanced by three observations. First, the proven systems that support POE were designed in the 1970s. A decision must be made to install an old "tried-and-true" system or to be part of a new experiment. Either course has risks. Second, POE requires change in the way health professionals work. To have a good outcome, they must put their time into the implementation effort not just at the beginning but in an ongoing fashion. Third, POE must be part of a comprehensive clinical information management environment. Physicians readily appreciate the advantage of clinical data retrieval and "smart" POE systems need clinical data to work.

Physician order entry may well come into common use during the decade of the 1990s. The potential benefits of POE are compelling. Health care is one of the last major industries to rely on pen and paper for the majority of its record keeping. Health care reform will lead to changes in clinical practice and teaching patterns. A shift to POE can be incorporated into those changes. With proper planning, POE may lessen the impact of these changes by incorporating state-of-the-art information management into the physician's work patterns.

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(Sorted chronologically by year and alphabetically by first author within each year. References to the Proceedings of the Annual Symposium on Computer Applications in Medical Care [SCAMC] are referenced by copyright date. For meetings that occurred between 1991 and 1993, the copyright date is one year after the meeting date.)

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