Predicting computerized physician order entry system adoption in US hospitals: Can the federal mandate be met?

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Abstract:

Objectives: The purpose of this study is four-fold. First, the hospitals' current level of computerized physician order entry (CPOE) adoption is reported; second, internal and external influence factors' roles in determining CPOE adoption rates are described; third, the future diffusion rate of CPOE systems in US hospitals is empirically predicted; finally, the current technology's state-of-the-art is assessed.

Data source: Secondary data from 3 years of the Leapfrog Group's annual survey (2002–2004) of US tertiary-care hospitals.

Study design: This study estimates CPOE market penetration rates applying technology diffusion theory and Bass modeling techniques for three future CPOE adoption scenarios—'Optimistic,' 'Best estimate', and 'Conservative' are empirically derived. *Principal findings:* Two of the CPOE adoption scenarios have diffusion S-curve that indicates a technology will achieve significant market penetration. Under current conditions, CPOE adoption in urban hospitals will not reach 80% penetration until 2029.

Conclusions: The promise of improved quality of care through medication error reductions and significant cost controls prompted the Institute of Medicine to call for universal CPOE adoption by 1999. However, the CPOE products available as of 2006 represent only a 'second generation technology', characterized by many limitations. Without increased external and internal pressures, such CPOE systems are unlikely to achieve full diffusion in US hospitals in a timely manner. Alternatively, developing a new generation of CPOE technology that is more 'user-friendly' and easily integrated into hospitals' legacy systems may be a more expedient approach to achieving widespread adoption.

Keywords: Computerized physician order entry, Quality control, Medical informatics, Health information systems, Medical errors

Article:

1. *Introduction*

The combination of President Bush's 2004 executive order establishing the Office of the National Coordinator for Health Information Technology tasked with ensuring implementation of electronic health records (EHRs) nationwide by 2014 and the Institute of Medicine's recent call for the use of electronic prescribing systems in all health care organizations by 2010 heighten urgency around the need to accelerate computerized physician order entry (CPOE) system adoption in US hospitals. These CPOE systems have the potential to improve patient safety and provide decision support at the point of care [1–5], thereby addressing major policy and practice issues around quality of care and practice variation that are of widespread concern [6–13].

Yet the CPOE systems currently available are costly, complex, and potentially increase ADE rates if not effectively implemented [14–18]. Further, doctors have resisted adopting current CPOE systems because they require significant changes in their workflows [19–21]. Therefore, the question becomes: are the CPOE systems commercially available today likely to be widely adopted by US hospitals by the 2010 recommendation called for by the IOM? And, if not, what is the predicted time horizon for adoption?

The purpose of this study is to answer these questions by developing three empirical models that predict likely adoption patterns for CPOE systems based on currently available data about CPOE system adoption and use. In this paper, we first describe the Technology Diffusion Model (TDM) which we use to frame our analysis based on 3 years of the Leapfrog Group's annual hospital survey (2002–2004) of CPOE adoption. Next, we apply diffusion modeling techniques to quantify and graphically display predicted CPOE implementation trends among urban US hospitals. Finally, we discuss our findings, limitations of the current study, and areas for future research.

2. Study data and methods

2.1.The Technology Diffusion Model (TDM)

Everett Rogers' diffusion of innovations model identifies five patterns of adoption among potential technology users: innovators (i.e., first adopters), early adopters, early majority, late majority, and laggards [22]. This theory has been successfully applied in studies of health information technologies (HITs) to categorize different types of adopters, and is used to frame our study as well [23]. Additional research by Bass described the function of *external* and *internal influences* in his empirical modeling of factors predicting the diffusion patterns for new technologies [24]. In the diffusion of innovations literature, these external influences are often referred to as *innovation factors*, and include those influences driven by information sources considered outside a provider's social system. External factors promoting CPOE adoption include pressures from policymakers (e.g., the IOM report); purchasers, and consumer advocates (e.g., the Leapfrog Group and the eHealth Initiative). Internal influences on a potential adopter's decision about a new technology originate within that provider's social system and are commonly labeled as *social contagions* in the diffusion literature [25]. In the case of CPOE systems, the presence of CPOE system champions or use of other integrated systems might be social contagions. For example, if referring physicians begin to use CPOE extensively, surgeons may find it advantageous to adopt the technology. Alternatively, if a physician finds using other electronic system features advantageous, such as receiving lab reports, the doctor may adopt the CPOE feature. To model such diffusion modes Bass models are commonly used.

The Bass model predicts how many customers will eventually adopt a new product, and when they will do so, based on early market penetration rates. The basic formula for calculating the percentage of adopters at any point, using discrete time notation, can be written as: [26]

$$F(t) = \frac{1 - e^{-(p+q)t}}{(1 + (q/p)e^{-(p+q)t})}, \qquad (1)$$

where $F(t)$ =the number of adoptions occurring in period t, p = coefficient of innovation, capturing the intrinsic tendency to adopt, and the effect of time invariant external influences, q =coefficient of imitation or social contagion, capturing the extent to which the probability that one adopts (given that one has not yet done so) increases with the proportion of eventual adopters who have already opted in, and t= period of measurement.

To forecast the adoption path of a new product with a diffusion model, the researcher assigns values for the model's parameters based on experiences with comparable goods. From a marketing perspective, this is problematic because realistic forecasts for new product adoption are needed early on in the product's life, when very little data exists. However, once sufficient adoption level data become available, usually after three or more periods, the researcher can then estimate p and q using the basic Bass model (Eq. (1)). In the case of CPOE, empirically derived point estimates of hospitals' adoption levels are relatively rare, but growing. However, there has been one survey that has been in the field for 3 years that allows an estimate to be made.

2.2.Data source and sample

The data for this study were provided by the Leapfrog Group. In the case of CPOE systems in healthcare, the Leapfrog Group's annual survey of urban–tertiary hospitals is considered primary with respect to measuring hospitals' CPOE adoption levels. The first 3 years of surveys conducted by the Leapfrog Group thus provide the basis for estimating the factors that predict future CPOE adoption levels.

Three samples were drawn from the 3-year Leapfrog survey dataset to generate our 'Optimistic,' 'Best,' and 'Conservative' estimates of *external influence* and *internal influence* on diffusion measures (see Table 1). The Optimistic estimate uses the 661 hospitals' data that responded to all 3 years of the survey (2002–2004). The Optimistic estimate's underlying assumption is that survey non-respondents have adopted CPOE systems at the same rate as survey respondents. However, it stands to reason that if a hospital was meeting the CPOE adoption criteria, it would be in its interest to report that fact and derive the competitive benefit of differentiating itself on that dimension of quality.

The 'Best' estimate does not make the equal adoption rate assumption of the Optimistic scenario. Instead, the inclusion criteria are relaxed to take in the 1007 hospitals that were targeted or volunteered information in all 3 survey years. Our operational assumption for the Best estimate scenario is that if a hospital had a CPOE system, or was planning to adopt one, it would have reported that fact. The Best estimate's starting point (2.89%) is also the closest to other reported estimates for the observed periods [27].

Table 1 – Leapfrog hospital survey CPOE adoption rates 2002–2004

Sampling scenarios	2002		2003		2004	
	n	CPOE systems fully implemented (%)	*n*	CPOE Systems fully implemented (%)	*n*	CPOE systems fully implemented (%)
Optimistic estimate	661	29 (4.39)	661	32 (4.80)	661	37 (5.60)
Best estimate	1007	29 (2.89)	1007	32 (3.18)	1007	37 (3.67)
Conservative estimate	1188	33 (2.78)	1510	42 (2.78)	1655	50 (3.02)

Source: Authors' analysis of the Leapfrog Group's Hospital Patient Safety Survey (2002–2004).

The 'Conservative' estimate includes all of the hospitals targeted in each survey year. As a result, this estimate has an escalating number of observations from year to year. Historically, the survey's response rate has improved as multiple years of requests are made, other hospitals in the market respond, and the Leapfrog initiative enters the public's consciousness. Nevertheless, it does take time for the reporting imperative to gain traction. Therefore, the Conservative scenario may underestimate the total number of CPOE adopters in the marketplace due to a systematic lag in reporting. Future iterations of the survey and further refinement of the instrument's variables will likely produce increasingly accurate adoption level estimates.

2.3. CPOE diffusion variables

Medstat, on behalf of the Leapfrog Group, gathers hospitals' survey responses and applies an algorithm developed by the Group's patient safety expert panel to generate a single-item score for CPOE adoption (see https://leapfrog.medstat.com/ for a full description of the algorithm). The scale has five response levels. The highest level of adoption is 'Fully Implemented' (level 1) and indicates that at least 75% of all a hospital's medication orders are transmitted via a CPOE system. The next two highest levels of adoption, labeled 'Good Progress' (level 2) and 'Good Early Stage Effort' (level 3), indicate that a hospital is moving toward the 'Fully Implemented' standard within the next two (level 2) to three (level 3) years. The final two reporting levels are 'Willing to Report Publicly' (level 4) and 'Did Not Disclose Information' (level 5). Hospitals that fail to progress through the adoption levels from 1 year's survey to the next have their scores lowered as part of the evaluation algorithm.

For purposes of our study, the CPOE adoption variable was dichotomized between hospitals reporting a 'Fully Implemented' CPOE system and other. This new variable served as the numerator in the annual CPOE adoption percentage. As described above, the denominator for the annual adoption percentage was varied according to the sampling strategy to create three adoption rates for each year. This methodology was chosen for two reasons. First, the purpose of the study is to assess *full* CPOE implementation rates. Second, the mutable nature of the other achievement levels significantly complicates the modeling. The statistical extrapolation was conducted in Microsoft Excel using the linear optimization tool.

2.4. Data analysis: derivation of the external and internal influence factors

We conducted the statistical extrapolation in Microsoft Excel, using the linear optimization tool. Our object was to have unique estimates for *external* and *internal influence* coefficients that would approximate the known CPOE adoption percentages as closely as possible for all 3 survey years. The objective function was the summed differences between the estimated and actual adoption levels for the 3 known years, and the target value was zero or as close to zero as possible. We applied one constraint to the optimization routine. The difference between the actual and estimated percentages of adopters for any year had to be less than 0.5% in absolute terms.

3. Study results

3.1. Statistical estimates of CPOE diffusion curves

We estimated the coefficients of external (p) and internal (q) influences estimated for all three CPOE diffusion scenarios. Table 2 presents the three diffusion scenarios' external and internal influence coefficients, their tipping points, and the projected maximum market penetration levels. The Optimistic and Best estimate scenarios display the characteristic S-curve that is indicative that, given enough time, CPOE systems are likely to achieve significant market penetration. The Conservative estimate is a positively sloped straight line, indicating that CPOE systems may not achieve a large market presence in the foreseeable future without a significant change in the systems' features.

Fig. 1 presents the CPOE diffusion curves based on the standard Bass Model of Innovation Diffusion and estimates of hospitals' CPOE adoption rates as presented in Table 2. Based on the 2002–2004 Leapfrog Survey data, fewer than 1% of hospitals had more than 90% of orders entered using electronic systems [28]. This finding is consistent with the initial IOM report's findings for that period and provides external validity to our study's analyses. Our extrapolated models indicate that CPOE system diffusion will take at least 20 years to reach a 50% adoption level in the marketplace. The implications of these findings for policymakers and other stakeholders are discussed next.

4. Discussion

The results of our study indicate that the current, commercially available CPOE systems are unlikely to achieve significant market penetration as desired by 2010. Therefore, the answer to the first question posed in this article is *no*.

Table 2 – Diffusion coefficient estimates, tipping points, and CPOE adoption rates

Scenario estimates	External diffusion coefficient (p)	Internal diffusion coefficient (q)	Tipping point	Max. CPOE adoption %[a]
Optimistic	0.0085	0.0673	2025	72.16%
Best	0.0049	0.1143	2024	85.81%
Conservative	0.0058	0.0000	n.a.[b]	n.a.[b]

Source: Authors' analysis of the Leapfrog Group's Hospital Patient Safety Survey (2002–2004).
[a] Both the Best and Optimistic scenarios are extrapolated to 2040. Future adoption rates may reach higher levels in later periods.
[b] The Conservative scenario does not follow the traditional diffusion S-curve. Therefore, it does not have a tipping point.

While the Optimistic and Best estimate scenarios do indicate that CPOE technology will eventually achieve significant market penetration, this is predicted to occur only in relatively distant timeframes. The answer to the second question motivating this project is that it will take at least 10 years longer than hoped for by the IOM and President Bush. The Conservative, or worst case, scenario is particularly troubling for those hoping to promote the CPOE system adoption among hospitals as its time horizon extends well into the future, with only 20% adoption predicted by 2038.

The Best and Optimistic estimates' S-shaped diffusion curves indicate that CPOE technology is gaining traction in US hospitals, though perhaps not as quickly as desired by policymakers. The relatively slow pace of adoption at the beginning of the Best estimate picks up speed and surpasses the Optimistic scenario's diffusion rate in 2018 and continues to accelerate in subsequent years. However, the Best estimate's coefficient of *internal influence* is relatively low compared to diagnostic technologies such as CT scanners (q =.367) and Ultra-sound imaging (q =.51), which achieved greater than 90% market penetration within 15 years of their introductions [29]. Congruent with similar research into EMR adoption among physicians' groups [30], CPOE systems do not appear likely to achieve the widespread use hoped for by policymakers and patient safety advocates.

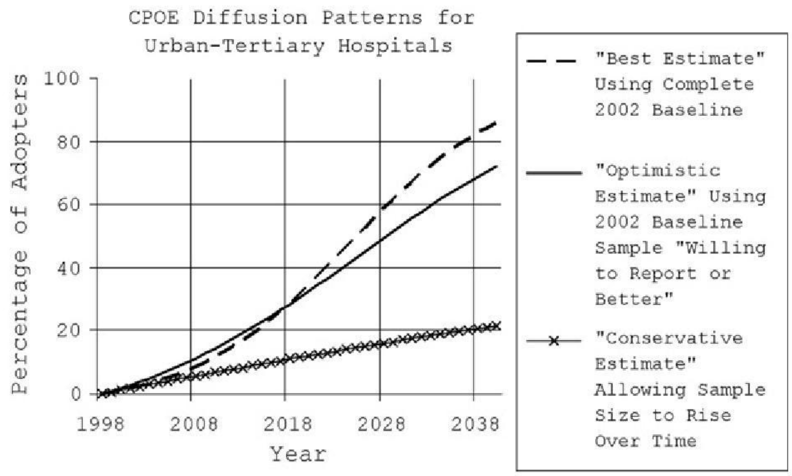

Fig. 1 – Three models of CPOE diffusion for urban–tertiary hospitals. *Source*: Authors' analysis of the Leapfrog Group's Hospital Patient Safety Survey (2002–2004).

The evolution of CPOE systems has proceeded gradually since the first one was introduced in 1969 [31]. However, as seen in many technology diffusion efforts, high-technology products often require three, or even four, successive generations of product innovations and marketplace substitutions to achieve full diffusion [32]. Even when systems are adequately well developed, implementation can take extended periods of time [33] depending upon factors idiosyncratic to the organization [34]. For CPOE systems, there are still significant questions about the efficacy of the state-of-the-art. Given that the pace of product evolution likely impacts adoption and diffusion, innovation progress may accelerate adoption rates, but adoption may still proceed slowly, as our analyses predict.

Several trends in the healthcare marketplace and literature support the likelihood of a longer time horizon as predicted by all three of our scenarios. First, there have been several reports of costly CPOE system implementation failures [35]. Combined with the added costs and expected resistance to system introduction, these well-known barriers may cause administrators to take a wait-and-see approach to adoption. Next, in many settings, a fully usable CPOE system depends on the existence and interoperability of other technologies and systems [36]. Thus in many organizations, the need to for an operational electronic medical record (EMR) may be a rate-limiting first step constraining implementation of a CPOE system. In addition, the ability to integrate CPOE systems into other existing information technologies, such as legacy billing systems, can slow adoption. Third, and potentially more problematic for CPOE proponents, is the emergence of empirical studies questioning CPOE's clinical efficacy [37–39]. Given that these trends directly impact the two major adoption stakeholders –hospital administrators and clinicians – the barriers to CPOE adoption may be greater than previously estimated [40].

On the other hand, some trends are helping to speed CPOE adoption. First, newer physicians' increased familiarity with all forms of IT is changing their expectations for clinical systems in the hospital environment, creating new internal influences on technology innovation [30]. Therefore, a new generation of end-users is systematically replacing the current cohort of physicians that is resisting the adoption of CPOE technologies. As a result, is likely that this new generation of physician users will force improvements and drive a new wave of CPOE system innovation that meets their changing clinical and practice needs.

A second trend in the marketplace is the increased demand for more electronically compiled clinical information in support of payment claims documentation. It is becoming increasingly impractical to have post hoc entry of orders and other diagnostic information as more detail is required. Medicare, in particular, both has the leverage and has indicated that it is moving in this direction with programs such as the Premier pay-for-performance demonstration [41,42]. In technology diffusion terms, such changes to payment schemes represent important new external influences that may also affect technology innovation and adoption rates. Thus, combined, CPOE technology, the population of end-users, and health care environment are all coevolving in a way that will accelerate diffusion in the future.

5. Study limitations

First, because we use Leapfrog data for our predictions, our study results are limited by the quality of these data. Given that Leapfrog data are self-reported survey data, our results are subject to the limitations consistent with such survey methodologies. Specifically, there is the potential for biases, including upward bias from respondents who give socially desirable answers to questions reflecting innovation and innovativeness, or confusion about definitions of CPOE systems. As these biases tend to inflate estimates of CPOE adoption, it is possible that even our conservative estimates of adoption trends in the future are overstated, thus highlighting the need for additional rigorous study of adoption trends.

Second, while the Leapfrog data represent a wide distribution urban US hospitals, our results cannot be generalized to rural hospitals. However, given that rural areas typically have lower rates of CPOE adoption than urban hospitals, it is likely that our findings would be even less optimistic if rural hospitals were included in our predictions.

Third, from a theoretical perspective, it is possible that the diffusion of CPOE systems will not follow the predicted S-shaped adoption curve, but instead be discontinuous. This is particularly possible if external influences and new product innovations create new incentives for CPOE adoption. Under such circumstances, it is likely that our predicted adoption timeframes may be shortened, yet it remains highly unlikely that CPOE system adoption will be widespread in the near term.

6. Future research

Future research that frames cross-national comparisons of external influences such as government incentive programs and their effects on diffusion factors could help inform efforts to encourage CPOE adoption. For example, empirical information on how physicians and other care providers react when the government introduces standards and mandates would be useful. In addition, further exploration of the Leapfrog Group’s datasets studying hospitals’ intentions to adopt, the nature of the systems implemented and the success or failure of those efforts would be particularly beneficial to organizations and policymakers attempting to accelerate CPOE adoption among US hospitals.

7. Concluding comments

One question motivated this study: are the CPOE systems commercially available today likely to be widely adopted by US hospitals in the near term? Based on 3 years’ of hospitals’ CPOE adoption level data and prospective modeling of innovation diffusion, the evidence strongly suggests that the answer is *no*. The next question then emerges: what is the nature of the challenge facing policymakers and private entities trying to accelerate the rate of CPOE diffusion in hospitals?

Several articles have outlined the potential barriers to CPOE adoption and all of these articles identify the current level of CPOE technology capability as an inhibiting factor in accelerating the diffusion process [11,16,20,27,43]. Measures to promote diffusion, such as providing financial incentives, demonstrating CPOE systems clinical efficacy, and developing better implementation strategies may increase the number of adoptions at the margin. However, incentive programs do not address the root cause of the slow diffusion problem. Namely, the products commercially available as of 2006 are perceived to have a relatively low ROI by administrators, are not considered user-friendly by physicians, are difficult to integrate with legacy systems, and have a high implementation failure rate. In addition, considerable time has passed since the introduction of CPOE systems in US hospitals, resulting in a long "intergenerational period" for this technology [44]. As slow progress in product innovation has been found to negatively impact subsequent technology adoption rates.

With high expectations that new clinical IT such as CPOE systems can assist in efforts to reduce medical errors, improve care quality, and reduce inappropriate variation in care, it becomes imperative to direct resources to support this effort. Beyond verbal commitments, financial resources must be funneled toward development of enhanced technology capabilities in health care. Proper oversight and investment can help guide technology development with appropriate attention to data standards, cost-effectiveness, requirements for workflow adaptation, and potential clinical impact. By considering the concerns and requirements of the multiple stakeholders, technology development can proceed in a more effective manner that meets users' needs, and is well positioned to diffuse, as policymakers hope.

Summary points

What was known before the study?

- There were some estimates of the number of hospitals currently using or implementing CPOE systems, but none had estimated the trajectory of diffusion.

- The *Technology Diffusion Model* has been used extensively in other industries to accurately predict the rates at which consumers will adopt new products.

- Groups advocating Pay-for-Performance (P4P) models have been at the forefront of the patient safety movement calling for increased use of health information technology to deliver care.

How this research adds to our understanding?

- We created three estimates predicting the rates of CPOE adoption using longitudinal data and the Technology Diffusion Model.

- The 'Best Estimate' indicates that CPOE adoption will not reach the levels targeted by advocacy groups or the US government without significant interventions.

- The CPOE technology currently available may not ever achieve full adoption in US hospitals.

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