

Cost-Benefit Analysis of a Hospital Pharmacy Bar Code Solution

Saverio M. Maviglia, MD, MSc; Jane Y. Yoo, MPP; Calvin Franz, PhD; Erica Featherstone, BS; William Churchill, PharmD; David W. Bates, MD, MSc; Tejal K. Gandhi, MD, MPH; Eric G. Poon, MD, MPH

Background: Bar coding can reduce hospital pharmacy dispensing errors, but it is unclear if the benefits of this technology justify its costs. The purpose of this study was to assess the costs and benefits and determine the return on investment at the institutional level for implementing a pharmacy bar code system.

Methods: We performed a cost-benefit analysis of a bar code–assisted medication-dispensing system within a large, academic, nonprofit tertiary care hospital pharmacy. We took the implementing hospital's perspective for a 5-year horizon. The primary outcome was the net financial cost and benefit after 5 years. The secondary outcome was the time until total benefits equaled total costs. Single-variable, 2-variable, and multiple-variable Monte Carlo sensitivity analyses were performed to test the stability of the outcomes.

Results: In inflation- and time value–adjusted 2005 dollars, total costs during 5 years were \$2.24 million (\$1.31 million in 1-time costs during the initial 3.5 years and

\$342 000 per year in recurring costs starting in year 3). The primary benefit was a decrease in adverse drug events from dispensing errors (517 events annually), resulting in an annual savings of \$2.20 million. The net benefit after 5 years was \$3.49 million. The break-even point for the hospital's investment occurred within 1 year after becoming fully operational. A net benefit was achieved within 10 years under almost all sensitivity scenarios. In the Monte Carlo simulation, the net benefit during 5 years was \$3.2 million (95% confidence interval, –\$1.2 million to \$12.1 million), and the break-even point for return on investment occurred after 51 months (95% confidence interval, 30 to 180 months).

Conclusion: Implementation of a bar code–assisted medication-dispensing system in hospital pharmacies can result in a positive financial return on investment for the health care organization.

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Author Affiliations: Brigham and Women's Hospital (Drs Maviglia, Churchill, Bates, Gandhi, and Poon and Ms Featherstone), Harvard Medical School (Drs Maviglia, Bates, Gandhi, and Poon), and Partners Healthcare Systems (Drs Maviglia, Bates, and Poon), Boston, Mass; Medical College of Virginia, Richmond (Ms Yoo); and Eastern Research Group, Lexington, Mass (Dr Franz).

MEDICATIONS ARE THE most frequent cause of adverse events.¹ More than a million injuries and nearly 100 000 deaths are attributable to medical errors annually.² Although few medication errors result in adverse drug events (ADEs),³ hospitals incur \$2200 in additional costs per ADE^{4,5} and \$4685 per preventable ADE.⁶ Nationally, the cost of ADEs is \$2 billion per year.⁶

Computerized physician order entry (CPOE) can prevent serious ordering errors by up to 55%.⁷ However, many medication errors occur in the dispensing, transcribing, and administering stages of the medication process.⁸ Although medications picked from inventory are routinely checked and double-checked, 3% to 6% contain an error,^{9,10} and only 34% of dispensing errors and 2% of administra-

tion errors are intercepted before patient exposure.¹¹ Given the high volume of medications dispensed by a hospital pharmacy, even a modest reduction in the overall error rate might avert many preventable ADEs.¹²

Recently, we studied medication-dispensing error rates at our institution before and after the implementation of a bar code–assisted dispensing system.¹³ Before bar coding, 0.19% of dispensed doses had errors with the potential to harm patients (potential ADEs, usually incorrect medication, strength, or dosage form). After implementing bar coding, the rate of potential ADEs from dispensing errors decreased to 0.07%. With approximately 6 million doses dispensed annually, this represents approximately 7260 averted potential ADEs annually. Although not all potential ADEs lead to actual ADEs, the savings from this technology may be substantial.

Unfortunately, the cost of this technology is also substantial. Individual health care institutions have limited resources and must choose from several error-reducing interventions¹⁴ and investments. Overall, it has been difficult to compare interventions because relatively little is known about their cost-effectiveness. The purpose of this study was to assess the costs and benefits and determine the return on investment at the institutional level for implementing a pharmacy bar code system.

METHODS

SETTING AND OVERVIEW

Brigham and Women's Hospital (BWH) is a 735-bed, tertiary, academic, nonprofit medical center. Its inpatient pharmacy service dispenses approximately 6 million medication doses for 35 000 admissions annually. The hospital employs 61 full-time pharmacists, 45 full-time pharmacy technicians, and 2500 registered nurses, who are responsible for most medication administration.

At BWH, all physician orders are entered into a locally developed inpatient CPOE system.⁷ Medication orders are sent electronically to the pharmacy information system, approved by pharmacists, and then executed throughout the hospital. Commonly used medications are stocked in semiautomated medication-dispensing devices in the nursing units, whereas less commonly used medications are filled from the pharmacy, dispensed in unit doses, and stored in patient-specific drawers before administration.

In 2001, BWH allocated \$3 million to build a state-of-the-art bar code and electronic medication administration record system to reduce the rate of pharmacy dispensing and nursing administration medication errors. The project was implemented in phases. During the pharmacy phase of the project, bar codes were affixed to all medications at the unit-dose level. These bar codes were scanned to ensure that the correct medications at the correct dose, strength, and form were being dispensed. This article focuses on the costs and benefits associated with this bar code-assisted dispensing system.

INTERVENTION

Approximately 60% of pharmaceuticals at BWH lacked acceptable unit-dosed bar code labels. Therefore, BWH established an on-site drug repackaging center to provide 100% bar-coded unit-dose medications. This procedure required significant changes to the physical plant and staff workflows. For example, pharmacy staff now had to scan bar codes as they stocked and withdrew medications from a newly installed carousel system (White Systems TD0860-130, series 2400, with software version 3.1.1 beta; Omnicell, Mountain View, Calif) to ensure that the correct medication, form, dosage, and quantity were being dispensed.

COSTS AND BENEFITS

All relevant incremental costs from the hospital's perspective were included. Direct capital costs included software development (mainly integration with the BWH CPOE and pharmacy systems), hardware purchases (ultraportable laptop computers, scanners, and equipment for the pharmacy repackaging center), and changes to infrastructure (wireless local area network). Also included were preimplementation planning costs incurred by key individuals who met with vendors, evaluated products, and made decisions about new pharmacy proce-

dures and workflow. In addition, both initial and periodic training costs due to staff turnover were included.

Recurring costs included the incremental time required for staff to support the system and repackage medications that did not have standard bar codes. It also included direct costs, such as the lease agreements for the repackaging center and carousel system, and operating and maintenance costs for equipment.

The primary benefit was the cost savings associated with preventing ADEs. Dispensing error rates were measured before¹⁵ and after implementation,¹³ and then the error reduction rate was applied to the total dispensed doses to calculate the expected number of avoided errors. Only errors with the potential to harm patients (potential ADEs) were considered, and only those that actually would have resulted in an ADE were assigned a financial value. Estimates from the published literature about the proportion of dispensing errors that are intercepted (34%),¹¹ the rate at which potential ADEs result in actual ADEs (13.4%),³ and the average incremental cost to the hospital of preventable ADEs (\$4600 in 1995 dollars)⁶ were used to translate error reduction rates to dollars saved. Because the savings from an averted ADE accrue to the hospital only under a prospective payment system, the savings were multiplied by the proportion of such patients at our institution (73%).

The primary outcome was the net financial cost and benefit during the initial 5-year period from preimplementation planning through development and roll-out. The secondary outcome was the time when total benefits equaled total costs. Also calculated were the cost of bar coding per ADE averted and the return on investment at 5 years (computed as the internal rate of return for a periodic series of cash flows).

DATA COLLECTION

Primary data were collected from various sources. Direct capital costs were determined from BWH accounting records. Individuals responsible for preimplementation planning filled task grids to document the time spent on the bar code project. Whenever possible, these time logs were cross-checked with objective records, such as calendar archives and attendee lists from meeting minutes (Microsoft Outlook; Microsoft Inc, Redmond, Wash). Time spent managing, programming, testing, debugging, and integrating software and hardware was extracted from an electronic project management system (Planview, version 7.2; Planview Inc, Austin, Tex). Training hours for pharmacists and pharmacy technicians were tallied from training session attendance records. All hours were converted into dollars based on wage rates provided by the BWH human resources department or from other salary data compilation sources (eg, <http://www.salary.com>) when this information was unavailable; an additional 30% was added to account for fringe benefits.

The impact on pharmacy workflow was determined by direct observation, before and after intervention, of the time pharmacy technicians spent dispensing medications. Their efficiency, expressed as doses dispensed per hour, was converted to dollars through wage information. On the basis of collective pharmacist report, training of new personnel was thought to be time neutral compared with training before the bar-coding system was implemented. Furthermore, no significant change was noted in staff turnover after the implementation of bar coding.

Benefits were calculated from directly observed rates of potential dispensing errors both before¹⁵ and after the intervention.¹³ A dispensing error was defined as any discrepancy between dispensed medications and physician orders or replenishment requests or any deviation from standard pharmacy policies. Potential ADEs were defined as dispensing er-

Table 1. Input Variables to the Monte Carlo Simulation*

Monte Carlo Input Variable	Mean (SD)	Source
Doses affected by bar coding, %	84.0 (1.5)	Poon et al ¹³
Pre-bar coding potential ADE rate, %	0.19 (0.013)	Cina et al ¹⁵
Post-bar coding potential ADE rate, %	0.07 (0.005)	Poon et al ¹³
Rate of interception of potential ADEs, %	34.0 (7.6)	Leape et al ¹¹
Potential ADEs resulting in actual ADEs, %	13.4 (5.9)	Bates et al ³
Cost per preventable ADE, \$	4600 (2067)	Bates et al ⁶
Prospective payment rate, %	72.5 (0.2)	2003 BWH billing data
Repackaged doses per month, No.	402 655 (2799)	Measured
Cost per repackaged dose, \$	0.07†	Per contract
Carousel leasing cost, per dose, \$	0.03†	Per contract
Pre-bar coding fill rate, doses per hour	161†	Measured
Post-bar coding fill rate, doses per hour	192†	Measured

Abbreviations: ADE, adverse drug event; BWH, Brigham and Women's Hospital.

*Normal distributions were used for all inputs, except for the cost per preventable ADE, for which a γ distribution was used. Not shown are inputs for labor and capital (see Figures 1 and 2).

†Indicates that a 10% variance was assumed.

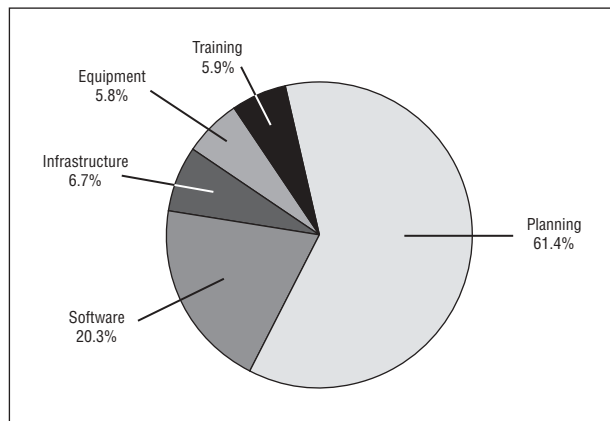


Figure 1. Components of 1-time costs of the pharmacy bar-coding project. The total of the 1-time costs was \$1.3 million in 2005 dollars. Percentages do not total 100% because of rounding.

rors with the potential to harm patients; potential ADEs were further classified as life threatening, serious, or significant based on a previously validated 2-physician panel algorithm.¹⁵

STATISTICAL ANALYSES

Costs and benefits were aggregated by fiscal quarter and analyzed with Microsoft Excel 2003 (Microsoft Inc). Costs and benefits were converted to constant 2005 dollar values using the Producer Price Index for General Medical and Surgical Hospitals.¹⁶ Future costs and benefits were discounted from the project start date (October 1, 2001) to adjust for the time value of money. We assumed that the discount rate for costs equaled the discount rate for benefits. Because the nominal prime interest rate averaged 5% between 2001 and 2005,¹⁷ whereas annual inflation averaged 2.4% during the same period,¹⁶ we assumed a real annual discount rate of 3% for the primary analysis.

SENSITIVITY ANALYSES

One-way sensitivity analyses were performed on all nonmeasured data inputs, such as discount and inflation rates, the pro-

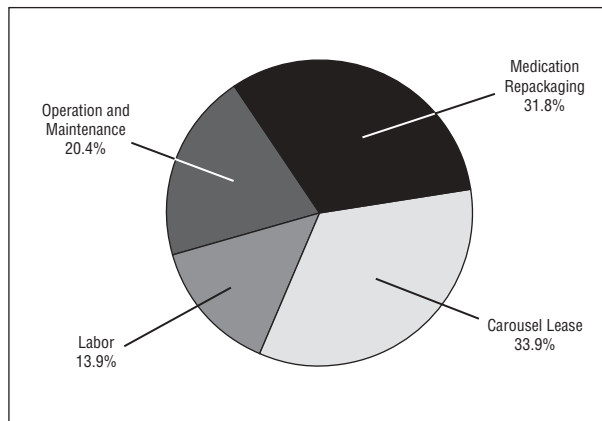


Figure 2. Components of recurring costs of the pharmacy bar-coding project. The total of the recurring costs was \$342 000 annually in 2005 dollars.

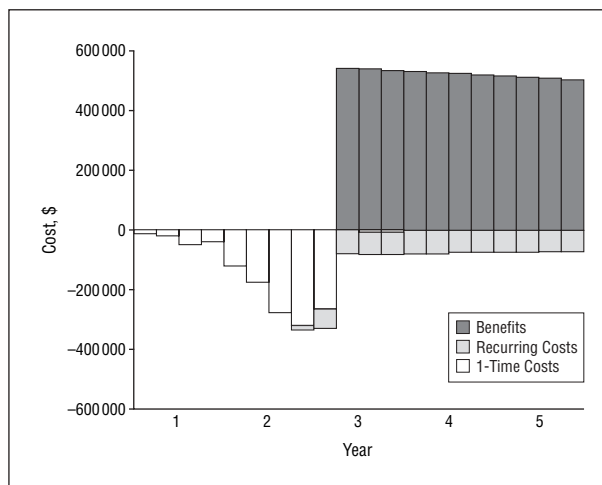


Figure 3. Cost expended and benefits accrued (in time-discounted 2005 dollars) each quarter of the pharmacy bar-coding project time line.

portion of dispensing errors that resulted in ADEs, and the cost savings from an averted ADE. Furthermore, the effect of adjusting all collected data upward or downward by 25% was also evaluated. Because the primary outcome depended heavily on the benefits side of the equation, further sensitivity analyses were performed, including a 2-way analysis of cost per ADE with prospective payment rate, a 2-way analysis of the parameters used to estimate actual ADEs from observed rates of dispensed errors, and an analysis restricted only to serious adverse events.

Finally, all cost and benefit inputs were simultaneously varied in a Monte Carlo simulation (@RISK, version 4.5 for Excel; Palisade Corp, Ithaca, NY). Normal distributions with base case mean values were used as the inputs with 2 conservative exceptions. First, because the output of the model depended greatly on the cost per ADE, which was estimated from the literature rather than measured, a γ distribution was used to skew the distribution of this input to lower values. Second, because the recent historically low interest and inflation rates on which the 3% real annual discount rate was based might not reflect the future, the Monte Carlo simulation assumed a normal distribution centered on 5% for this input. Actual measured standard deviations were used when available, such as for the error rate distributions before and after bar code system implementation (**Table 1**); otherwise, a standard deviation of 10% of the mean was assumed.

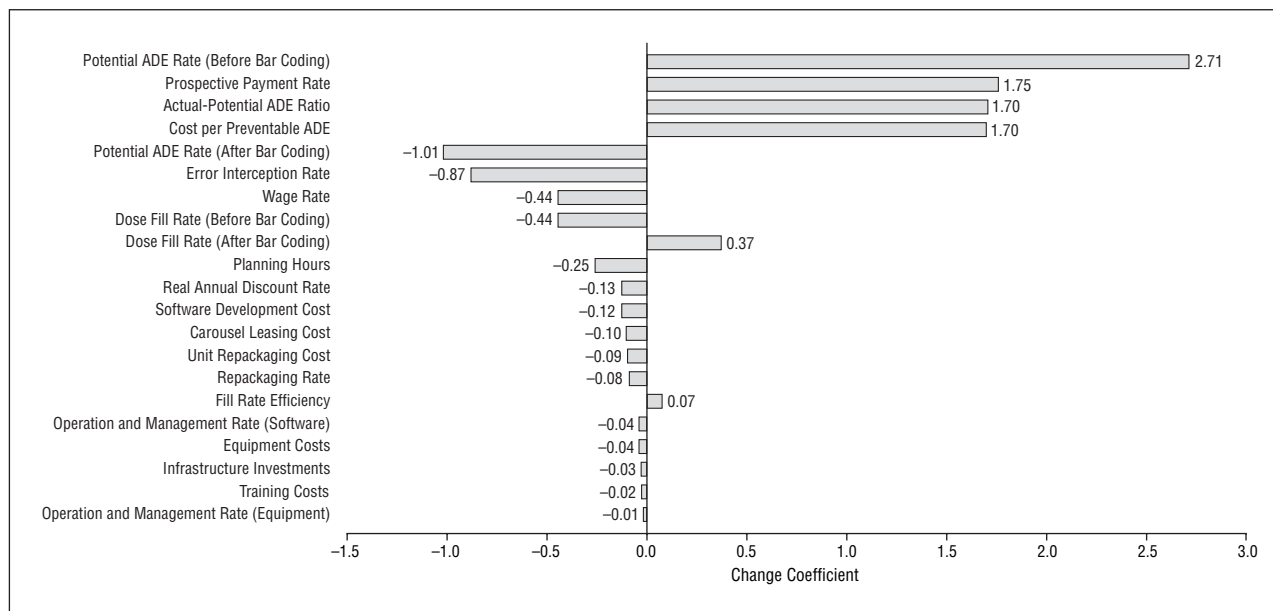


Figure 4. Results of 1-way sensitivity analyses for each of the input variables. Change coefficient is the ratio of the percent change in the net cumulative net benefit at 5 years compared with the percent change in the input variable. ADE indicates adverse drug event.

Table 2. Years Until Cumulative Benefit Equals Cumulative Cost as a Function of Estimated Cost per ADE and the Hospital's Prospective Payment Rate

Prospective Payment Rate, %	Average Cost per ADE, \$							
	1500	2000	2500	3000	3500	4000	4500	5000
40.0	33.00	10.25	7.00	5.50	4.75	4.25	4.00	3.75
50.0	12.00	7.00	5.25	4.50	4.00	3.75	3.50	3.50
60.0	8.00	5.50	4.50	4.00	3.75	3.50	3.25	3.25
70.0	6.50	4.75	4.00	3.75	3.50	3.25	3.25*	3.00
80.0	5.50	4.25	3.75	3.50	3.25	3.25	3.00	3.00
90.0	5.00	4.00	3.50	3.25	3.25	3.00	3.00	3.00
100.0	4.50	3.75	3.50	3.25	3.00	3.00	3.00	2.75

Abbreviation: ADE, adverse drug event.

*Boldface indicates the scenario that most closely approximates the base case.

RESULTS

The total cost during 5 years was \$2.24 million in inflation- and time value-adjusted 2005 dollars. This amount consisted of \$1.31 million in 1-time capital investments for planning, development, and rollout (**Figure 1**) followed by \$342 000 annually in recurring costs (**Figure 2**). Notably, planning expenses made up 61% of the 1-time costs.

The rate of potential ADEs decreased 63%, from 0.19% of dispensed doses before the implementation of bar coding to 0.07% afterward.¹³ Assuming that 34% of the potential ADEs would have been intercepted¹¹ and 13.4% of the remainder would have resulted in actual ADEs,³ this corresponded to 517 averted ADEs annually, a savings of \$2.2 million annually. Throughout 5 years, the cumulative benefit was \$5.73 million (the system became fully active in year 3).

The net benefit throughout 5 years was \$3.49 million, and the break-even point for return on investment occurred during the first quarter of year 4 or within the

first year of operation. **Figure 3** shows how costs were expended and benefits accrued through the 5-year period, corresponding to an annualized return on investment of 104%. The average cost of bar coding per averted ADE was \$1573 through year 5, then only \$661 per averted ADE thereafter (ie, after achieving steady state).

One-way sensitivity analyses showed that the outcomes were relatively insensitive to the cost inputs (**Figure 4**). The cost factor with the biggest impact on primary outcome was the wage rate; a 10% increase in this input caused a 4.4% decrease in the net cumulative benefit at 5 years. In all cases in which a cost input was varied, return on investment (break-even point) occurred within the first year of operation.

The primary and secondary outcomes were more sensitive to the assumptions that went into calculating benefits (Figure 4). For example, a 10% increase in the pre-bar coding potential ADE rate decreased the 5-year net cumulative benefit by 27%. Therefore, more detailed 2-way sensitivity analyses were performed for these variables (**Tables 2, 3, and 4**). However, even in the worst-case

Table 3. Years Until Cumulative Benefit Equals Cumulative Cost as a Function of the Estimates of the Rate at Which Potential ADEs Result in Actual ADEs and the Percentage of Potential ADEs That Are Intercepted Before Reaching the Patient

ADEs Intercepted Before Reaching Patient, %	Potential ADEs That Result in Actual ADEs, %						
	5.0	7.5	10.0	12.5	15.0	17.5	20.0
20.0	4.50	3.50	3.25	3.00	3.00	2.75	2.75
30.0	5.00	3.75	3.50	3.25*	3.00	3.00	2.75
40.0	6.00	4.25	3.50	3.25	3.00	3.00	3.00
50.0	7.50	4.75	4.00	3.50	3.25	3.25	3.00
60.0	11.75	6.00	4.50	4.00	3.50	3.50	3.25

Abbreviation: ADE, adverse drug event.

*Boldface indicates the scenario that most closely approximates the base case.

Table 4. Years Until Cumulative Benefit Equals Cumulative Cost as a Function of Pre-Bar Coding and Post-Bar Coding Potential ADE Rates

Post-Bar Coding Potential ADE Rate, %	Pre-Bar Coding Potential ADE Rate, %							
	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21
0.05	3.50	3.25	3.25	3.00	3.00	3.00	3.00	3.00
0.06	3.50	3.50	3.25	3.25	3.00	3.00	3.00	3.00
0.07	3.75	3.50	3.50	3.25	3.25	3.25*	3.00	3.00
0.08	4.25	3.75	3.50	3.50	3.25	3.25	3.00	3.00
0.09	4.75	4.25	3.75	3.50	3.50	3.25	3.25	3.00
0.10	5.75	4.75	4.25	3.75	3.50	3.50	3.25	3.25

Abbreviation: ADE, adverse drug event.

*Boldface indicates the scenario that most closely approximates the base case.

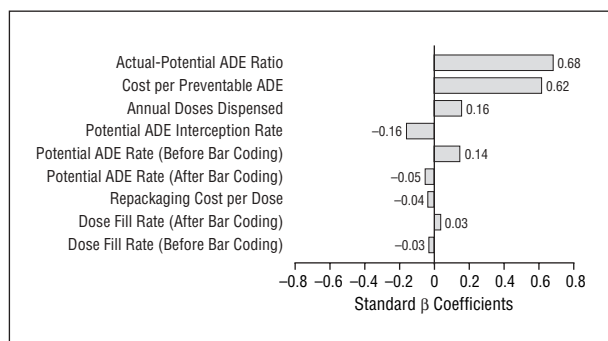


Figure 5. Inputs with the largest effects on the Monte Carlo simulation output (time value-adjusted cumulative net benefit at 5 years). Standard β coefficients are the change (in standard deviation units) in the output variable caused by a 1-SD change in the input variable. ADE indicates adverse drug event.

scenario examined, in which the average savings from an averted potential ADE was set at only \$1500 and the prospective payment rate was only 40%, bar coding still eventually paid for itself. Most scenarios in the 2-way analyses, as well as a 1-way analysis of reducing annual doses dispensed to 1.75 million, achieved net positive cumulative benefits by year 10. Finally, since the cost per ADE was based on a study of mostly preventable ordering and administration errors,⁶ whose severity distribution may differ from that of preventable dispensing errors, we also performed an analysis restricted to serious or life-threatening potential ADEs. In that scenario, return on investment occurred in the 10th year, with the average cost per averted ADE of \$5711 through year 5 and \$2401 thereafter.

The Monte Carlo simulation corroborated these findings. The net benefit throughout 5 years was \$3.25 million (95% confidence interval [CI], -\$1.22 million to \$12.07 million), and the break-even point for return on investment occurred after 51 months (95% CI, 30 to 180 months). In only 1.6% of the simulations did the intervention never achieve a positive net benefit. The average cost per averted ADE was \$1976 (95% CI, \$609 to \$5613) during the first 5 years and \$873 (95% CI, \$207 to \$2542) after steady state. The Monte Carlo simulation was most sensitive to the percentage of potential ADEs resulting in actual ADEs; every standard deviation increase in this variable caused a 0.68-SD increase in net benefits throughout 5 years (Figure 5), a 0.29-SD decrease in time to break even, and a 0.72-SD decrease in the cost per averted ADE.

COMMENT

Across a broad range of assumptions, investment in a hospital-based pharmacy bar-coding system for dispensing medications was not only favorable but was cost saving from the hospital's perspective within a 5- to 10-year horizon. This is similar to the results of a recent cost-benefit analysis of CPOE at this institution,¹⁸ which measured a \$9.5 million net benefit during 10 years and a break-even point of 7 years. Since the medication-dispensing process is distinct from the medication-ordering process, the cost savings from pharmacy bar coding is likely to be independent of what might be obtained from CPOE.

A strength of this study is that detailed prospectively measured costs and benefits were used, and when primary data were unavailable, published estimates rather than expert opinion were used. Although one may dispute the 2 most important determinants of benefit, namely the proportion of dispensing errors that result in ADEs and their cost, the analysis appeared to be robust when these variables were varied widely.

Of course, whether the implementation of a bar code–assisted medication-dispensing system is successful or not ultimately depends as much on the implementation as on the system itself, both of which can introduce errors.^{19,20} Although the method used to measure preintervention and postintervention error rates¹³ counted all errors that slipped passed the quality control processes in place for the system as a whole, different results may have been observed if the same system had been implemented with less planning or staff training.

Although this study assessed the value of pharmacy bar coding, it did not evaluate other potential investments the hospital could have made with its funds. As previously mentioned, the costs and benefits of inpatient pharmacy bar coding are comparable to those of CPOE. Until similar cost-benefit analyses of other error-reducing strategies are performed, both computer and non-computer based, such as increased pharmacist staffing or decreased patient-nurse ratios, no conclusion can be made about the relative value of pharmacy bar coding compared with these other interventions.

This study took the implementing hospital's perspective. From a societal perspective, the costs would largely be the same, but the benefits would be greater because they would also include benefits to the patient, such as reduced pain and suffering, decreased length of stay, and averted lost income. Therefore, a societal cost-benefit analysis would be more positive than that reported herein, suggesting that payers and purchasers should support hospitals without enough capital to fund the up-front costs of this technology.

This study had several limitations. It was conducted at a single large academic institution with a rich computer-based decision support infrastructure, and the results may not be generalizable to smaller community-based hospitals without such an infrastructure. However, the fact that hospital pharmacies across the nation use similar standardized medication-dispensing processes²¹ with similar pre-bar code dispensing error rates¹⁵ suggests that the benefits of bar coding this process can be reproduced widely. Furthermore, neither CPOE nor bar code–assisted medication administration is a prerequisite for implementing this technology. It requires only the presence of a computerized pharmacy system, which most hospitals have.²¹

Certainly, the size of the hospital, or more precisely the number of dispensed annual doses, matters. Keeping costs constant, return on investment within 10 years was achieved with annual doses of at least 1.75 million. However, it is likely that smaller hospitals would have lower expenses as well. Also, the fact that bar coding of unit-dose medications by manufacturers is now mandated²² implies that a portion of the costs measured in

this study (that associated with repackaging) might be avoided or reduced.

The institution in this study decided to build its own software and lease its repackaging equipment. Other hospitals may choose a different combination of lease, buy, or build options. As the technology matures and vendors produce more products, it is likely that these options will become cost competitive with each other and therefore will not influence the net benefit significantly.

Finally, the study design was based on a pre-post comparison of error rates. A randomized controlled trial design was not possible with such a large systemwide intervention. However, the pre- and postintervention periods were temporally close, and no other significant changes were made in the medication-dispensing process during the transition to bar coding. Furthermore, no significant changes were noted in other pre-post measurements, such as dispensing volume, case mix and severity, or prospective payment rates.

In conclusion, this study demonstrated that a hospital-based pharmacy bar-coding system for dispensing medications was cost saving within a 5- to 10-year time frame across a wide range of assumptions. These data may be helpful to hospitals in prioritizing implementation of bar coding among other investments being considered.

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Correspondence: Saverio M. Maviglia, MD, MSc, Clinical Informatics and Research Division, Partners Healthcare System, 93 Worcester St, PO Box 81905, Suite 201, Wellesley, MA 02481 (smaviglia@partners.org).

Author Contributions: The primary author had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* Maviglia, Bates, and Poon. *Acquisition of data:* Maviglia, Yoo, Featherstone, Churchill, Bates, and Poon. *Analysis and interpretation of data:* Maviglia, Yoo, Franz, Bates, Gandhi, and Poon. *Drafting of the manuscript:* Maviglia and Yoo. *Critical revision of the manuscript for important intellectual content:* Maviglia, Franz, Featherstone, Churchill, Bates, Gandhi, and Poon. *Statistical analysis:* Maviglia, Yoo, and Franz. *Obtained funding:* Maviglia, Bates, Gandhi, and Poon. *Administrative, technical, and material support:* Yoo, Featherstone, Churchill, and Bates. *Study supervision:* Maviglia and Poon. *Analysis and modeling:* Franz.

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