CLINICAL INVESTIGATION

Medication Waste Reduction in Pediatric Pharmacy Batch Processes

Matthew F. Toerper, BS,^{1,2} Michael A. Veltri, PharmD,^{3,4} Eric Hamrock, MBA,² Nicole L. Mollenkopf, PharmD,³ Kristen Holt, PharmD,⁵ and Scott Levin, PhD^{1,2}

Departments of ¹Emergency Medicine and ⁴Pediatrics, Johns Hopkins University School of Medicine, Baltimore, Maryland, ²Operations Integration, Johns Hopkins Health System, Baltimore, Maryland, ³Pediatric Division, Department of Pharmacy, and ⁵Department of Pharmacy, Johns Hopkins Hospital, Baltimore, Maryland

OBJECTIVES: To inform pediatric cart-fill batch scheduling for reductions in pharmaceutical waste using a case study and simulation analysis.

METHODS: A pre and post intervention and simulation analysis was conducted during 3 months at a 205-bed children's center. An algorithm was developed to detect wasted medication based on time-stamped computerized provider order entry information. The algorithm was used to quantify pharmaceutical waste and associated costs for both preintervention (1 batch per day) and postintervention (3 batches per day) schedules. Further, simulation was used to systematically test 108 batch schedules outlining general characteristics that have an impact on the likelihood for waste.

RESULTS: Switching from a 1-batch-per-day to a 3-batch-per-day schedule resulted in a 31.3% decrease in pharmaceutical waste (28.7% to 19.7%) and annual cost savings of \$183,380. Simulation results demonstrate how increasing batch frequency facilitates a more just-in-time process that reduces waste. The most substantial gains are realized by shifting from a schedule of 1 batch per day to at least 2 batches per day. The simulation exhibits how waste reduction is also achievable by avoiding batch preparation during daily time periods where medication administration or medication discontinuations are frequent. Last, the simulation was used to show how reducing batch preparation time per batch provides some, albeit minimal, opportunity to decrease waste.

CONCLUSIONS: The case study and simulation analysis demonstrate characteristics of batch scheduling that may support pediatric pharmacy managers in redesign toward minimizing pharmaceutical waste.

INDEX TERMS: computer simulation, cost control, medical waste, pharmacy service, hospital

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INTRODUCTION

Prescription drug expenditures for US hospitals have risen to more than \$32 billion annually.¹ Provider ordering practices and pharmacy production and delivery processes can lead to significant pharmaceutical waste. Wastage rates in hospitals have been reported as between 16.6% and 28.7% dependent on the types of pharmaceuticals examined, type of hospital, and patient population served.^{2–6} Much of this waste stems from batch preparation and scheduled delivery of non-urgent, patient-specific medication. Patient-specific medications make up a high proportion of doses produced by pediatric hospital pharmacies (estimated at 85% for the pharmacy studied) because of weight-based customization.

Although advance preparation is required to ensure that medications are available to patients when needed, it has the potential to yield waste when doses are discontinued after preparation.^{2–7} Discontinuations result from clinical decisions to stop medication or alter dosage, frequency, administration route, or administration time. In addition, discontinuations occur from patient discharges that were uncertain at the time of medication order placement. Discontinued patient-specific medications cannot be returned to stock because of their unique customization. Standardized medications are also not typically reused because they must be checked for tamper evidence and relabeled prior to medication expiration, which is often not practical.

Hospitals incur large costs for pharmaceutical

waste from discontinuations.⁸ This has triggered several hospital pharmacies (pediatric and adult) to initiate efforts to decrease waste, with reductions spanning from 31% to 85%, totaling \$60,000 to \$426,244 in annual cost savings.²⁻⁶ Many of these interventions focused solely on intravenous medications, not accounting for other types. They were also multifaceted, improving several aspects of hospital-based pharmacy services. However, paramount to each was significant redesign to the cart-fill (i.e., batch) schedule. Despite the success of these initiatives, many pediatric pharmacies face barriers in the effort and costs required for redesign and implementation of a new batch schedule.^{2,7}

To aid in redesign, systems engineering tools, such as computer simulation, are capable of determining the effects of many different batch schedules prior to implementation. Simulation analysis has proven to be effective in a variety of ways to support decision-making for process change in pharmacies.^{7,9-14} This includes simulation efforts to determine the effects of automated dispensing on patient waiting,¹⁰ improve turnaround times,¹¹⁻¹⁴ balance pharmacist workload over time,¹⁴ and reduce waste.^{7,13} However, many institutions may not have the resources to create their own in-house simulation model. In this context, we present a simulation analysis used to analyze the batch schedule of a pediatric hospital pharmacy. This analysis provides general insights that may guide pediatric pharmacy managers to redesign batch schedules for reducing waste. Readily available facility-specific information about medication volume and timing of orders may be used to determine an optimal schedule. Further, the cost of medications and labor for delivery may be estimated to examine trade-offs toward the most cost effective design.

MATERIALS AND METHODS

The pre-post and post- intervention and simulation analysis was conducted at a 205-bed children's center within an academic tertiary care hospital. The pediatric pharmacy division is located within the children's center, serving all patients within these units. The pharmacy operates completely independently of the larger hospital system. Pharmaceuticals both administered and wasted were studied during 3 months between June and September 2012, with the results an-

nualized. All parenteral and non-parenteral medications prepared in the batching process were included in the analysis. Exclusions were topical medications, continuous infusions, controlled substances, intravenous fluids available in patient care areas through automated dispensing, and select items produced using a separate just-in-time process. Exclusions fell outside of the batching process and were not eligible.

Time-stamped medication orders, medication administration times, and discontinuation times were retrospectively collected from the computerized provider order entry (CPOE) system. Providers (most commonly nurses) in the children's center are required to document the status of all medication administration tasks. Medications administered to the patient are documented as "performed." Medication orders that were discontinued prior to administration time result in medication tasks documented as "canceled." A small proportion (2.1%) of medication tasks may also be documented as "not performed." In these instances, the provider chose not to administer the medication at the scheduled time; however, the medication order is still in place for the future. In addition, acquisition costs were collected for each medication and assumed to be the costs lost for waste. Costs of delivery were estimated to be \$117 per batch based on time-for-labor and wage rates. The costs of labor to prepare each medication were difficult to estimate and thus were excluded from our analyses.

Pre-and Post Intervention Analyses

The redesigned batch schedule during the study period was a 3-batch-per-day process (6:30 AM print time to noon delivery time; 1:45 PM to 7 PM; and 5:15 PM to 2 AM). This batch process was instituted in April 2012 after the relocation of the pediatric pharmacy to a new clinical building. The batch redesign was informed by some of the same analysis described in this paper; this analysis was conducted between March and June 2011. The batch schedule prior to relocation was a single batch per day (6 AM print time to 3 PM delivery time). There was a significant increase in the number of pediatric beds and changes in patient mix after relocation, which limited our ability to perform an unbiased preintervention and postintervention analysis. However, using simulation we explicitly modeled both the pre-relocation (1 batch per day) and postrelocation (3

batches per day) schedules during the postrelocation study period to produce fair comparisons.

Simulation Methods

A deterministic simulation model estimating pharmaceutical waste and associated costs under many practical batching schedules was developed. Deterministic models contain known inputs, including CPOE information (i.e., medication orders, administration times, and discontinuation times) and a specific batch schedule. The deterministic approach uses the same CPOE information regardless of the specific batch schedule simulated. This was based on the assumption that providers place medication and discontinuation orders as needed for patient care, with minimal consideration for batching processes.¹⁴ The output for each simulated schedule included the proportion of medication wasted and associated costs.

A structured query language algorithm was developed to detect wasted medication based on a simulated batch schedule. For the prerelocation, 1-batch-per-day (6 AM print time to 3 PM delivery time) schedule, medication is prepared for the following 24-hour service window (3 PM same day to 3 PM the next day). Medications from this batch that were discontinued (i.e., canceled) within the service window and during batch preparation were considered waste. This included all medications that were delivered to hospital units and not administered because discontinuation preceded scheduled administration. Medications documented as “not performed” were also considered waste because of ad hoc clinical decisions to withhold medications at their scheduled administration time. This was independent of batch scheduling and held constant across all simulated batches. The algorithm was able to compute the total cost of waste for each batch schedule by summing acquisition costs linked to medications detected as waste.

The study analyzed 108 batch schedules spanning from 1 to 6 batches per day and including both the actual prerelocation and postrelocation batching schedules. When any of the simulated scenarios with 2 or more batches was simulated, the service window between batches was spread equally throughout the day. This was done to keep the simulation scenarios tractable and isolate the effects of batch frequency from batch timing. The first 58 of our batching scenarios were

developed according to pharmacy-provided time-duration estimates. Time for batch preparation in these 58 scenarios was fixed at: 9 hours (1 batch per day), 7 hours (2 batches per day), 6 hours (3 batches per day), 5.5 hours (4 batches per day), 5 hours (5 batches per day), and 4 hours (6 batches per day). Under batch preparation time and service window constraints, the batch schedule was then shifted hour by hour over the day to determine the impact of timing. Finally, we developed an additional 50 batch schedules that simulated time-duration reductions in optimized batches. The simulations allowed for the study of many batch scenarios, leading toward general and practical concepts that minimize pharmaceutical waste and its costs.

RESULTS

During the study period, an average of 1864 medication doses were prepared per day, with an SD of 248 doses per day. The total cost of all prepared doses was estimated to be \$3,488,025 per year. The prerelocation single-batch schedule was estimated to waste 28.7% of batched medications, costing \$686,752 annually. The postrelocation 3-batch schedule was estimated to waste 19.7% of batched medications, costing \$503,372. This represented a 31.3% reduction in waste and \$183,380 in cost savings annually. However, when costs of increased labor for delivery (\$85,410) are included, the net annual savings totaled \$97,970. In addition to pre-and post analyses, the simulation was used to study the isolated effects of batch schedule characteristics on pharmaceutical waste. This included the 1) frequency of batches per day, 2) batch schedule times, and 3) batch preparation time duration. Each of these characteristics may be examined sequentially to determine an optimal batching schedule.

Batch Frequency

Increasing batch frequency per day decreases the amount of time between preparation and administration of many medications. This facilitates a more just-in-time process that decreases the service time window, the amount of medication prepared per batch, and potential for waste. A total of 58 batch scenarios were simulated for between 1 and 6 batches per day. The average proportion of pharmaceutical waste for each batch frequency simulated may be seen in Figure

Figure 1. The effect of batches per day on percentage of doses wasted. SDs ranged from 0.2% to 0.6% for 2- to 6-batch frequencies; SD for 1 batch per day was 1.6%.

1. Averages are reported to isolate the effects of batch frequency on pharmaceutical waste, separate from batch timing. The most substantial gains occur by shifting from a schedule of 1 batch per day to at least 2 batches per day. This same pattern is demonstrated for corresponding costs of waste seen in Figure 2. However, when incorporating costs of delivery, producing more than 3 batches per day becomes less cost-effective at the institution studied. Although the pediatric pharmacy studied pays fixed costs for each batch delivery (hence, additional costs of more frequent delivery may offset cost savings from reduced waste), some institutions might be able to implement delivery methods that reduce delivery costs as batch frequency rises or combine batch deliveries with ad hoc medication deliveries. Such institutions may be able to substantially reduce the cost of delivery. Thus, Figure 2 includes a plot that disregards delivery cost and a plot that uses the fixed cost for each daily batch delivery.

Batch Schedule Times

The timing of batch production has a significant influence on medication waste. The optimal times for batch preparation are dependent on medication administrations and discontinuations within the hospital. The hour-by-hour pattern of daily administrations and discontinuations at the children's center studied is shown in Figure 3. The simulation demonstrates that to minimize waste, avoid preparing batches during periods where discontinuations occur at the highest rate and position the end of the batch schedules as close as possible to peak medication adminis-

tration times, without overlapping. These periods to avoid will often coincide with physician rounding in many institutions and were between 8 AM and noon in the children's center studied (Figure 3).

This concept was tested within the simulation by comparing the worst- and best-timed batch schedules. The worst schedules overlapped batch

preparation with high discontinuation and/or high administration time periods. The best schedules avoided this. Results for single-batch-per-day schedules demonstrated a worst schedule wastage rate of 29.1% compared with the best schedule wastage rate of 24.0%. This represents a 17.5% decrease in volume of wasted medications solely from shifting batch timing. A 9.6% decrease in waste was found across 2-batch-per-day schedules, whereas higher-frequency batch schedules (≥ 3 per day) demonstrated decreases of 5% or less. Therefore, the timing of batch schedules has a significant effect on rates of waste, but this effect diminishes as batch frequency increases. Understanding when high rates of administration and discontinuations occur and avoiding batch preparation during those times may allow one to design optimal batch schedules.

Batch Preparation Time

Shortening batch preparation times provides opportunity to decrease waste. This reduces discontinuations during batch processing and can reduce the time between medication preparation and administration.

Preparation time per batch for the best simulated schedule in each daily frequency (i.e., 1-6 batches per day) was systematically reduced by a half hour until each batch duration reached a minimum of 2 hours. It is important to note that this contravened the pharmacy's batch duration estimates but was done to determine the full relationship between preparation time and waste. For example, the optimal single-batch-per-day schedule was changed from 9 hours of prepara-

Figure 2. The effect of batches per day on average pharmaceutical waste cost. SDs were between \$9,500 and \$13,000 for 3 to 6 batches per day; \$20,000 for 2 batches per day; and \$33,000 for 1 batch per day.
○, Cost of wasted medication; ■, Net cost of waste and delivery

tion to 8.5 hours, and continued to be reduced in half-hour increments. For 2-batch-per-day scenarios, preparation time was reduced from 7 hours to 6.5 hours, and so on, in half-hour increments; this incremental reduction results in a net reduction of 1 hour of preparation time because the batch is prepared twice per day.

The effects of preparation time reduction on waste are most pronounced for higher-frequency batch schedules. For single-batch-per-day schedules, 1 hour of decreased preparation time translates to an average of 0.9% reduction in waste with an SD of 0.2%. For higher-frequency batch schedules (i.e., 2-6 batches per day), 1-hour reductions lead to between 2% and 4% decreases in waste.

DISCUSSION

The case study and simulation analyses outline characteristics of batch schedules that have an impact on the production of pharmaceutical waste. The concepts and recommendations put forth must be interpreted within the context of practical issues, such as pharmacy staffing constraints, lifestyle considerations, and service requirements. These analyses, under practical considerations, aided pharmacy leadership in developing a 3-batch-per-day schedule that was implemented after hospital relocation. The change yielded reductions in pharmaceutical waste and cost savings that were substantial. In addition, systematic examination of batch fre-

quency, schedule, and preparation times using simulation was performed to serve as a general guide for developing batch schedules effective in mitigating waste.

Determining batch frequency is likely the most important component of redesign. Several hospital pharmacies have moved toward more frequent batching (i.e., 3-6 batches per day).²⁻⁶ Our simulation results suggest that pharma-

cies processing high volumes of medication and/or producing large amounts of waste will benefit substantially from shifting to at least a 2-batch-per-day schedule. However, decreases in waste beyond 2 batches per day become less significant. If delivery costs per batch are fixed, as in this study, more frequent batching has the potential to become less cost-effective (Figure 2).

Decreases in waste may also be gained by strategically timing batch preparation to avoid time periods where administration or discontinuations are frequent. The daily patterns of orders and discontinuations (Figure 3) are likely variable across hospitals, especially in non-academic facilities with no morning rounds. These patterns may vary seasonally and from changes in clinician practices and patient care needs. A limitation of our study was that CPOE data were collected during a 3-month period, not capturing potential variability throughout the year. Consistent communication between clinicians and hospital pharmacists is required to determine how best to respond to significant changes in medication ordering patterns. Despite hospital-specific patterns and variability, the principle of batch preparation avoiding overlap with peak administration or discontinuation times is likely generalizable. However, as batching becomes more frequent (i.e., ≥ 3 times per day), timing becomes less important in reducing waste.

Reducing overall batch preparation time was the final waste minimization strategy analyzed. Although we found a direct relationship between

Figure 3. Proportion of medication administrations and discontinuations by hour of day.

■, Medication administrations; ■, Medication discontinuations

batch duration and waste, additional labor may be required to achieve more rapid dose production. Quality standards and medication processing constraints may also prohibit faster preparation time. Physical limitations regarding distances between the pharmacy and inpatient units can further constrain reductions in time between medication preparation and availability on the hospital units.

Finally, the results of this case and simulation study may only be interpreted within the context of a single institution. Pharmacies preparing smaller volumes of medications or with lower waste rates (i.e., less frequent discontinuations) will likely not see decreases in waste or costs as significant as those reported in this study. Medication ordering patterns in other facilities may be very different from the results reported. In some hospitals, optimal batch scheduling may be challenging to implement and appropriately staff. However, the purpose of our simulation analysis was to demonstrate general concepts aiding pharmacy managers toward decreasing medication waste and realizing trade-offs.

Hospital-based pharmacies are operating in a changing health care environment with escalating demand for medication and increased complexity of preparation. At the same time, economic pressures are motivating inpatient pharmacies to become more efficient and decrease pharmaceutical waste. A major component of this is the batching process to prepare non-

emergent medications. The concepts described through simulation analysis inform redesign of batch schedules to reduce pharmaceutical waste.

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Abbreviations CPOE, computerized provider order entry

Correspondence Matthew F. Toerper, BS, 5801 Smith Ave., Davis Building, 2nd Floor, Baltimore, MD 21209, email: mtoerper@jhu.edu

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