Comparison of a hybrid medication distribution system to simulated decentralized distribution models

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Purpose. The results of a study to estimate the human resource and cost implications of changing the medication distribution model at a large medical center are presented.

Methods. A two-part study was conducted to evaluate alternatives to the hospital's existing hybrid distribution model (64% of doses dispensed via cart fill and 36% via automated dispensing cabinets [ADCs]). An assessment of nurse, pharmacist, and pharmacy technician workloads within the hybrid system was performed through direct observation, with time standards calculated for each dispensing task; similar time studies were conducted at a comparator hospital with a decentralized medication distribution system involving greater use of ADCs. The time study data were then used in simulation modeling of alternative distribution scenarios: one involving no use of cart fill, one involving no use of ADCs, and one heavily dependent on ADC dispensing (89% via ADC and 11% via cart fill).

Results. Simulation of the base-case and alternative scenarios indicated that as the modeled percentage of doses dispensed from ADCs rose, the calculated pharmacy technician labor requirements decreased, with a proportionately greater increase in the nursing staff workload. Given that nurses are a higher-cost resource than pharmacy technicians, the projected human resource opportunity cost of transitioning from the hybrid system to a decentralized system similar to the comparator facility's was estimated at $229,691 per annum.

Conclusion. Based on the simulation results, it was decided that a transition from the existing hybrid medication distribution system to a more ADC-dependent model would result in an unfavorable shift in staff skill mix and corresponding human resource costs at the medical center.

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The unit dose system of medication distribution is used frequently, though not universally, in hospitals in the United States.[1,2] A 2008 survey of hospital pharmacy practices revealed that for noncritical care patients, 86.7% of hospitals dispensed a majority (≥75%) of oral doses in unit dose form.[2] Additionally, 69.6% of hospitals dispensed a majority of parenteral medications in unit dose form for patients other than critical care patients. Advantages of the unit dose system include reduced medication errors, more efficient use of pharmacy and nursing personnel, improved drug control, more accurate patient billing for medications, and the reduction of inventories maintained on nursing units.[1]

In 2011, Pedersen and colleagues[3] found that 64.5% of hospital pharmacies were using automated dispensing cabinets (ADCs) as the primary method of first-dose delivery, while 27.2% were using a centralized

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manual system for dispensing first doses.[2] Similarly, 62.5% of hospitals were using ADCs as the primary method for delivering maintenance doses, with 28.9% using a centralized manual system. First doses and maintenance doses were prepared for inpatients using centralized automated systems (such as a dispensing robot) in 6.7% and 8.4% of hospitals, respectively.

The model in which all or most medications are stocked on patient care units in ADCs has several advantages and disadvantages. Advantages of a decentralized automated dispensing system include automation of controlled-substance inventory reconciliation processes, more accurate charge capture, improved first-dose turnaround time, improved nursing staff satisfaction, and, theoretically, reduced nursing labor.[4] Among the disadvantages of this type of distribution system, depending on the configuration and number of cabinets, the nursing staff's workload can actually increase. While the use of open matrix drawers in ADCs is becoming less prevalent, their continued use is a threat to the maintenance of accurate medication inventories and increases the potential for medication errors. Additionally, use of ADCs as the predominant medication distribution system may result in greater nurse manipulation of products (e.g., drawing a partial dose from a single-dose vial, splitting a tablet), and significant costs are incurred due to the duplication of medication inventory across the institution and the significant number of ADCs necessary to hold that inventory.

In order to evaluate the labor associated with alternative pharmacy medication distribution models, time standards for individual tasks in a multistep process may be generated; the sum of the task times represents the time necessary to complete the entire process. Direct observation of processes can be used to generate time standards for various tasks.[5] When performing direct observation, an observer records the start and stop times of the task being observed. That task is observed for multiple occurrences under different circumstances (e.g., night shift, day shift).

Several studies have demonstrated the value of computer simulation in health care settings generally and in hospital pharmacies specifically.[6-10] In most of these studies, computer simulation has been used to assess the benefits and limitations of different staffing or facility design scenarios. Simulation is of particular value in the modeling of complex systems with many interacting parts.[11]

In one published study, a simulation model was developed in order to assess several options for central pharmacy staffing at a 224-bed community hospital.[6] The investigators developed a model to assess three options for modifications to the staffing model: (1) changing the frequency of ADC restocking, (2) altering the time of day of cart-fill checking by a pharmacist, and (3) adjusting the level of technician staffing. The investigators simulated 18 scenarios, with the output variable of interest being the average time an order spent in the system at a given hour of day. The data gleaned from this modeling exercise provided the pharmacy management team with information necessary to make an informed decision about what changes should be made to the central pharmacy staffing model.

An industry-sponsored study evaluated how various medication dispensing models affected patient safety and the efficiency of medication dispensing workflows in seven hospitals.[11] The average daily census of the seven hospitals included in the study ranged from 100 to 616 patients, with the average number of medication orders processed per day ranging from 1596 to 4222. The investigators estimated the pharmacy labor (pharmacist and technician) required to dispense new medication orders and to provide replenishment doses (via cart fill or ADC restock). The investigators found that the total pharmacy labor required to support pharmacy dispensing depended on the relative percentages of medications dispensed through the three dispensing pathways (ADC, unit dose, and sterile preparation) and the tools and technology supporting each pathway. Computer modeling of medication distribution at a hypothetical 300-bed hospital demonstrated a linear relationship between the percentage of doses dispensed via the ADC pathway and daily pharmacy labor.[11] For a 300-bed hospital dispensing 4% of doses from ADCs, the daily pharmacy labor was 134 hours, 11 minutes, and 8 seconds (134:11:08), which decreased to 42:30:37 if 95% of doses were dispensed via ADCs. For each percentage point increase in doses dispensed from an ADC, pharmacy labor requirements declined by 4.1879 hours.

While the report of the results of the industry-sponsored study presented a compelling case for decentralized dispensing with ADCs, it is important to consider that the report was prepared and distributed by a vendor of ADCs and was not peer reviewed.[11] Thus, it is possible that the findings of this study may have been biased in favor of a primarily ADC-based system. Additionally, the analysis did not evaluate the nursing labor associated with the various pharmacy dispensing systems.

The continued nationwide shift from centralized to decentralized medication dispensing systems in health-system pharmacy as well as other, internal factors prompted an analysis of the medication distribution system at the University of Wisconsin Hospital and Clinics (UWHC). The purpose of the analysis was to determine the most efficient and cost-effective method of distribution of medications to inpatient units at UWHC.

Background

UWHC is a 561-bed academic medical center that includes a 62-bed freestanding children's hospital. The pharmacy department at UWHC uses a hybrid medication distribution system in which controlled substances and many as-needed medications are dispensed from ADCs on nursing units. The majority of scheduled maintenance doses are dispensed from the central pharmacy as part of a 24-hour cart fill using automation (i.e., centralized robotic and medication carousel technologies). The daily cart fill is sent from the electronic health record (EHR) to the pharmacy automation system, which is programmed to begin filling at midnight; cart-fill doses are filled for administration times starting at noon extending through 11:59 a.m. on the following day. Thus, each cart fill dispenses doses that are for administration up to 36 hours in the future. The filled patient cassette drawers are delivered to patient care units by 11:00 a.m., at which time the contents of the newly filled cassette drawer are added to the drawer that is already on the unit. Discontinued and expired medications are removed from patients' medication drawers on a daily basis by pharmacy technicians who function in a decentralized manner.

Methods

The objectives of the study were (1) to analyze the hybrid medication distribution system in place at UWHC, (2) to analyze the decentralized medication dispensing system at a comparator institution, and (3) to use the resultant data to develop a model to simulate a decentralized medication distribution system at UWHC. The metrics of this study included

- The pharmacist, technician, and nurse labor necessary to support the medication distribution systems,
- The medication dispensing technology used to support the medication distribution systems, and
- The medication inventory required to support the medication distribution systems in select patient care areas.

The study sponsor (McKesson Corporation) had no role in study design and execution, data collection and analysis, and the writing of this manuscript. The primary investigator performed all data collection, model design, and data analysis and takes complete responsibility for the integrity of the data and the accuracy of the data analysis. The study was reviewed by the institutional review boards of UWHC and the comparator institution and deemed exempt, as it did not constitute human subjects research. The pharmacy and nursing staff members who were observed for this study were provided with both written and oral explanatory information on the study.

Analysis of hybrid medication distribution system at UWHC. The pharmacy workload associated with the 24-hour cart fill at UWHC was assessed. Observational time studies of the cart-fill process were performed over the course of four nights in order to generate time standards for each task that must be completed during the cart fill; this enabled the assessment of the total pharmacist and technician time dedicated to the cart fill each night. Direct observation was used to establish time standards because the majority of the tasks being observed were short in duration, occurred frequently, and had clearly defined start and stop times. Because direct observation time studies are subject to confounding by the Hawthorne effect, the results of these time studies were reviewed and validated by the study team, all of whom have extensive knowledge of pharmacy operations.

Workload statistics associated with each time standard were obtained from the integrated EHR and the interfaced pharmacy automation and technology application. Workload statistics for the cart fill included the average daily census, the total medication orders and doses filled, the numbers of medication doses and line items picked by the centralized dispensing robot and from the medication carousel, and the number of inpatient units for which doses were picked. There are two steps associated with the delivery phase of the cart-fill process: (1) technician delivery of cassette drawers to patient care units and (2) technician validation of doses in cassette drawers and removal of discontinued and expired medications. Time standards for these two steps were obtained from a recent unpublished workflow analysis at UWHC (personal communication, Dow JF; 2011 Apr).

The batch-restocking process used to maintain inventory levels within ADCs was observed and timed. Data from observation time studies of all activities of the process were recorded on the same pharmacy time-study form that was used for the cart-fill process. Time standards for medication line items from the medication carousel and from the narcotics vault were obtained and noted separately.

Workload statistics for the batch cabinet-restock process were obtained from the interfaced pharmacy automation and technology application and included the numbers of medication line items and doses picked from the medication carousel and from the narcotics vault, the number of inpatient units for which doses were picked, and the number of ADCs to which medications were delivered.

The nurse workload associated with obtaining medications and preparing them for administration within the existing medication distribution system was assessed. Observational time studies of nurses obtaining and preparing medications for administration were performed by the primary investigator. At the time of the study, UWHC nurses obtained medications from ADCs, medication cassette drawers, and other locations (e.g., refrigerators, areas with limited floor stock and central-supply-stocked items, delivery bins containing medications). The frequencies of obtaining medications from each location, queuing for ADC access, and doses requiring additional preparation (e.g., drawing injectable doses from single-dose or multidose vials, measuring bulk powders) were estimated from the observational data. The frequency of the reporting of medication doses as missing was obtained from data contained in a report from the integrated EHR. The number of cart-fill doses filled by the pharmacy was used as a proxy for the number of cart-fill doses obtained by nurses and ultimately administered to patients. Similarly, the number of medication line items obtained by nurses from ADCs over a 24-hour period was obtained from the interfaced pharmacy automation and technology system; those line items were assumed to represent the number of ADC line items obtained and ultimately administered to patients.

Time studies were performed on a medical unit and a surgical unit during both the morning and evening shifts. The start and stop times of each activity performed during a "medication obtaining event" were recorded, as were the numbers of doses obtained. The time required to log on to an ADC and the time required to obtain a dose from an ADC were collected separately to ensure that, when running the simulations, the time standard for logging on was applied only once for a medication obtaining event regardless of how many doses were obtained from the ADC (in general, a nurse only needs to log on to an ADC once whether he or she obtains 1 or 10 doses from the cabinet). The dosage forms of the medications that were obtained were recorded as well.

The number of ADCs and their configuration (main cabinet, auxiliary cabinet, or tower) on each inpatient unit at UWHC were assessed. The number of beds served by each cabinet was determined in order to calculate a bed-to-cabinet ratio. Data snapshots of the cost of the medication inventory maintained in ADCs on a medical unit, a surgical unit, and a critical care unit were obtained.

Analysis of the medication distribution system at a comparator institution. Indiana University Health—Bloomington (IUHB) was selected as the comparator hospital for this study because the pharmacy department uses unit-based ADCs as the primary method for the distribution of first doses and maintenance doses, has pharmacy automation and technology similar to UWHC's, was enthusiastic about participating in this study, and was located relatively near to UWHC.

IUHB is a 355-bed community hospital. Its pharmacy department employs a decentralized medication distribution system, with approximately 89% of all doses dispensed from unit-based ADCs that contain a standardized unit-specific inventory; the remaining 11% of doses are stored in patient-specific bins within an ADC tower. Replenishment of nonstocked medications occurs via a "mini-cart fill," which is picked from a medication carousel during the night shift and delivered the following morning. At IUHB, 25% of cabinets are restocked twice daily, and 75% are restocked once daily. Except as noted below, assessments of pharmacy and nursing time standards and workload statistics were performed in a manner similar to the studies performed at UWHC, as described above.

The primary investigator was onsite at IUHB for one week to perform time studies and gather workload data. Time studies of the batch cabinet-restocking process were performed over one day. Time studies of nurses obtaining medications and preparing them for administration were performed over the course of five nursing shifts. The observations of the nursing shifts at IUHB (as at UWHC) were split among medical and surgical units and day and evening shifts in order to observe all major medication administration times. Whereas at UWHC the nurses were able to obtain medication from three locations (an ADC, a cassette drawer, and other locations), there were only two locations at IUHB where medications were stocked: ADCs and patient-specific drawers within the ADC tower (doses in the patient-specific drawer were analogous to cart-fill doses at UWHC). The frequency of reports of missing doses at IUHB was assessed by evaluating requests for replacement doses sent by nurses documented in the EHR.

As at UWHC, the number of ADCs on each inpatient unit at IUHB and their configuration were assessed. Additionally, the number of beds served by each cabinet was noted in order to calculate a bed-to-cabinet ratio. These data provided an aggregate snapshot of the medication inventory maintained in ADCs on medical, surgical, and critical care units comparable to that obtained at UWHC.

Development of models to simulate a decentralized medication distribution system at UWHC. Commercially available simulation software (Process Simulator 2011, ProModel Corporation, Allentown, PA) was used to build and run simulation scenarios to determine the impact of implementing varying medication distribution systems on the pharmacy staff (pharmacists and pharmacy technicians) and nursing staff workloads at UWHC. Pharmacy workflows associated with the preparation and dispensing of medications included in the 24-hour cart fill and batch cabinet refills were visually represented as process maps within the simulation program. The nursing staff workflow of obtaining a medication dose and preparing it for administration (if needed) was also visually represented as a process map using data gathered from direct observations of that process. The process activities associated with the cart fill, batch cabinet refill, and nursing activities are listed in Tables 1 (pharmacy processes) and 2 (nursing staff processes). Human resources were assigned to each process step; the human resources included in the model were registered nurses, pharmacists, and pharmacy technicians.

Based on the workload statistics and time standards gathered at UWHC and IUHB, four simulation scenarios for cart-fill and ADC doses were developed: (1) all doses filled on a cart fill, (2) the existing medication distribution system at UWHC (the base case), with 64% of doses filled on a cart fill and 36% of doses obtained from ADCs, (3) a model analogous to the current medication distribution system at IUHB (11% of doses dispensed via cart fill and 89% of doses obtained from ADCs), and (4) all doses dispensed from ADCs. The workload statistics and time standards used to simulate each scenario are listed in Table 3. Because a finite number of observations of nursing and pharmacy personnel were conducted over a relatively short time frame, the results of direct-observation time studies were reviewed and validated by the study team.

Each scenario was simulated to determine the workload associated with the medication dispensing process for a one-day period at UWHC. Each scenario was run for 50 replications, out of which the average work times for each human resource were extracted and depicted graphically. The results of simulation modeling were expressed using descriptive statistics and confidence intervals, as well as charts and graphs.[12] The process of obtaining doses from locations other than ADCs and cassette drawers was not modeled in these scenarios, because those doses represent a small percentage of overall doses and including them in the analysis would have added significant complexity to the model. The number of ADC pockets restocked per dose administered was plotted against the percentage of doses dispensed from ADCs. The slope of this line was used to estimate the number of ADC pockets per day that would need to be restocked in the dispensing systems for which observational data were unavailable. Similarly, the probability of a dose being documented as missing and the average time spent looking for a missing dose were estimated by

Table 1.
Activities Observed During Pharmacy Time Studies and Associated Time Standards[a]

Process	Activity	Role	Time Standard (min:sec) UWHC	Time Standard (min:sec) IUHB
Cart fill	Print label for drawer	Technician	00:01.1	. . .[b]
Cart fill	Label drawer	Technician	00:04.0	. . .
Cart fill	Load drawer on conveyor	Technician	00:03.2	. . .
Cart fill	Robot picks doses	. . .	00:10.4	. . .
Cart fill	Remove drawer from conveyor and place on cart	Technician	00:05.1	. . .
Cart fill	Pick medication carousel doses	Technician	00:14.9	. . .
Cart fill	Pick remote medication carousel doses	Technician	00:23.8	. . .
Cart fill	Pick nonformulary/manual doses	Technician	00:43.9	. . .
Cart fill	Sort carousel, shelf, and manual doses into bin	Technician	00:00.9	. . .
Cart fill	Tech-check-tech of carousel, remote carousel, and manual doses	Technician	00:11.2	. . .
Cart fill	Pharmacist QA of tech-check-tech	Pharmacist	00:14.2	. . .
Cart fill	Remove discontinued medications	Technician	00:43.2	. . .
Cart fill	Deliver cart to unit	Technician	13:36.0	. . .
Cart fill	Compliance check	Technician	10:36.0	. . .
Cabinet fill	Pick medication carousel and remote medication carousel doses	Technician	00:21.3	00:25.0
Cabinet fill	Travel between units	Technician	01:47.4	01:15.2
Cabinet fill	Process returns to cabinet	Technician	00:26.8	01:10.3
Cabinet fill	Tech-check-tech of carousel and remote carousel doses	Technician	00:32.5	. . .
Cabinet fill	Restock ADC pocket	Technician	00:27.4	00:39.1
Cabinet fill	Pick controlled substances	Technician	00:25.6	. . .
Cabinet fill	Pharmacist QA of tech-check-tech	Pharmacist	00:16.1	00:07.0

[a]UWHC = University of Wisconsin Hospital and Clinics, IUHB = Indiana University Health—Bloomington, ADC = automated dispensing cabinet, QA = quality assurance.
[b]Not applicable.

plotting those parameters against the percentage of doses obtained from ADCs. This method was also used for the frequency of queuing for access to the ADC and the time spent queuing for access to the ADC. This type of estimate was not performed for the frequency with which additional manipulation of a dose was necessary, nor was it performed for the amount of time spent conducting those manipulations, because those parameters are more likely to be affected by differences in practice rather than the percentage of doses dispensed from ADCs.

A one-way sensitivity analysis was performed on the base case at UWHC for several model parameters. The minimum and maximum values for the sensitivity analysis were selected using the time standards and workload statistics obtained as described above. When no other data existed, parameters for sensitivity analysis were estimated as a function of the observed value (e.g., the observed value plus or minus 25%). The sensitivity analysis was performed to assess what model parameters had the greatest influence on the results of the simulation. The analysis indicated that the simulation model was relatively insensitive to the parameters that were associated with more uncertainty.

The medication dispensing technology required to support a decentralized dispensing system at UWHC was estimated independent of the simulation model. The bed-to-cabinet ratios and cabinet configurations for medical, surgical, and critical care units at IUHB were utilized to estimate the number and configuration of cabinets that would be required to support a decentralized dispensing system at UWHC. The cabinet inventories for a critical care unit at IUHB were used to develop a possible inventory for that unit type at UWHC; considerations were made for formulary status and practice differences.

Table 4 summarizes the sources of data on pharmacy workload, nursing workload, pharmacy automation and technology, and medication inventory at UWHC and IUHB. Data from the results of the simulations and the median hourly wage for employees from each discipline were used to project the daily and yearly changes in personnel costs[13] associated with a transition to a decentralized distribution model. Because it was unlikely that staffing patterns (e.g., nurse-to-patient ratios) would be changed as a result of changing the medication distribution model, these costs were viewed as opportunity cost. Thus, a positive cost indicates the value of additional time spent performing medication dispensing and preparation tasks that would be unavailable to perform other tasks (e.g., direct patient care activities).

The demographic data and workload statistics used to simulate the four medication distribution models are provided in Table 5; the simulation results are provided in Table 6.

Results

Hybrid medication distribution system at UWHC. Time standards for each cart-fill task based on data from the direct-observation studies are presented in Table 1. The time spent delivering cassette drawers to patient care units was 13 minutes and 36 seconds per unit. The technician time spent validating the doses in cassette drawers and removing discontinued and expired medications was 10 minutes and 36 seconds. Workload statistics associated with each time standard were obtained from the integrated EHR and the interfaced pharmacy automation and technology application (Table 5).

The time standards for each task associated with restocking ADCs were developed from direct-observation time studies (Table 1). The time standards for the nursing workflows observed are presented in Table 2.

At the time of the study, there were 26 large main ADCs, six small auxiliary cabinets, and nine large auxiliary cabinets to serve the inpatient units at UWHC. On average, the acquisition cost of medication inventory contained in ADCs at UWHC ranged from $390 in a pediatrics unit to $2618 in a critical care–burn care unit.

Medication distribution system at IUHB. Comparison of the time standards for the batch cabinet-restocking process at UWHC and at IUHB (Table 1) revealed a few key differences. The average time delivery technicians spent processing returns during the restocking process was longer at IUHB versus UWHC (1 minute and 10.3 seconds per cabinet versus 26.8 seconds per cabinet),

Table 2.
Activities Observed During Nursing Time Studies and Associated Time Standards[a]

Activity	Time Standard (min:sec) UWHC	Time Standard (min:sec) IUHB
Queue for access to ADC	00:35.8	01:54.0
Obtain dose(s) from ADC	00:33.3	00:25.6
Obtain dose(s) from cassette drawer	00:13.3	00:19.2
Obtain dose(s) from another location	00:16.5	. . .[b]
Prepare medication for administration	00:58.3	00:51.6
Alert pharmacy staff of missing dose	00:58.3	00:51.6

[a]UWHC = University of Wisconsin Hospital and Clinics, IUHB = Indiana University Health—Bloomington, ADC = automated dispensing cabinet.
[b]Not applicable.

in part because IUHB technicians also checked the expiration date of all patient-specific medications stocked in the ADC tower. Technicians at IUHB also took more time restocking ADC pockets than did technicians at UWHC (39.1 seconds per pocket versus 27.4 seconds per pocket). Finally, the pharmacist check of technician-picked doses for restocking ADCs was faster at IUHB (7 seconds per line item versus 16.1 seconds per line item).

Time standards for nursing workflows at IUHB are presented in Table 2. There were significant differences between UWHC and IUHB for nursing tasks related to obtaining and preparing medications for administration. On average, nurses at IUHB obtained medication doses from ADCs more rapidly than nurses at UWHC (25.6 seconds per line item versus 33.3 seconds per line item), likely because IUHB nurses obtained more line items during each trip to the ADC. Conversely, nurses at IUHB spent much more time queuing for access to ADCs than did nurses at UWHC (114 seconds per episode versus 35.8 seconds per episode). Nurses at IUHB also took more time to obtain a dose from a patient-specific bin than it took for nurses at UWHC to obtain a dose from a cassette drawer (19.2 seconds per dose versus 13.3 seconds per dose) because the IUHB nurses had to log in to the ADC to access the bin within the ADC tower.

Table 3.
Workload and Time-Study Data Used in Simulation Scenarios[a]

	Time Standard (min:sec), by Type of Distribution System			
Data Category	No ADCs (Scenario 1)	Hybrid (Scenario 2)	Decentralized (Scenario 3)	No CF (Scenario 4)
ADC technician time				
Check ADC restock line items	. . .[b]	00:32.5	00:32.5	00:32.5
Restock ADC pocket	. . .	00:27.4	00:27.4	00:27.4
Process returns to ADC	. . .	00:26.8	00:26.8	00:26.8
Travel between ADCs	. . .	01:47.4	01:47.4	01:47.4
Narcotic technician time				
Pick controlled-substance line item	. . .	00:25.6	00:25.6	00:25.6
Carousel technician time				
Pick medication carousel line item	. . .	00:21.3	00:21.3	00:21.3
Pharmacist time				
QA check ADC restock line item	. . .	00:16.1	00:16.1	00:16.1
QA check cart-fill line item	00:14.2	00:14.2	00:14.2	. . .
Decentralized technician time				
Compliance check of drawers for unit	10:36.0	10:36.0	10:36.0	. . .
Deliver cart to unit	13:36.0	13:36.0	13:36.0	. . .
Nurse time				
Obtain dose from drawer	00:13.3	00:13.3	00:13.3	. . .
Obtain dose from ADC	. . .	00:33.3	00:33.3	00:33.3
Prepare dose for administration	00:58.3	00:58.3	00:58.3	00:58.3
Queue for access to ADC	. . .	00:35.8	01:54.0	02:09.0
Locate missing dose	01:17.8	00:55.7	00:27.3	00:25.9
Cart-fill technician time				
Label cassette drawers	00:04.0	00:04.0	00:04.0	. . .
Load drawer into robot	00:03.2	00:03.2	00:03.2	. . .
Load drawer onto cart	00:05.1	00:05.1	00:05.1	. . .
Pick carousel line item	00:15.8	00:15.8	00:15.8	. . .
Sort carousel line item	00:00.9	00:00.9	00:00.9	. . .
Robot time				
Pick robot line item	00:10.4	00:10.4	. . .	. . .
TCT technician time				
Check nonrobot dose	00:11.2	00:11.2	00:11.2	. . .
CUD technician time				
Remove expired and discontinued doses from drawer	00:43.2	00:43.2	00:43.2	. . .

[a]ADC = automated dispensing cabinet, CF = cart fill, QA = quality assurance, TCT = tech-check-tech, CUD = central unit dose.
[b]Not applicable.

The probability of a nurse having to queue for access to an ADC was 7.2% at IUHB compared with 3.2% at UWHC. The most likely explanation for this difference was greater reliance on ADCs for first- and maintenance-dose dispensing at IUHB relative to UWHC (88.6% and 36.1% of doses dispensed from ADCs, respectively). Because significantly more doses were available for immediate administration at IUHB, it was not surprising that the frequency of missing doses was lower than at UWHC (0.45% versus 1.01%). A surprising finding was that additional dose manipulation before administration occurred more frequently at UWHC than at IUHB (14.29% of doses versus 5.8% of doses). This finding is likely due to differences in patient acuity between UWHC and IUHB as well as the hos-

Table 4.
Data Sources for Simulation Models[a]

Category	UWHC	IUHB
Pharmacy workload	• Direct observation • Assessment of staffing model • Pharmacy workload statistics	• Direct observation • Assessment of staffing model • Pharmacy workload statistics
Nursing workload	• Direct observation • Nursing workload statistics	• Direct observation • Nursing workload statistics
Pharmacy automation and technology	• Automation and technology used • Current automation and technology contracts • Department operating budget	• Automation and technology used
Medication inventory	• Snapshot of on-hand inventory	• Snapshot of on-hand inventory for select cabinets (medical, surgical, and critical care units)

[a]UWHC = University of Wisconsin Hospital and Clinics, IUHB = Indiana University Health—Bloomington.

Table 5.
Dispensing Data and Workload Statistics Used in Simulation Models[a,b]

Variable	No ADCs (Scenario 1)	Hybrid (Scenario 2)	Decentralized (Scenario 3)	No CF (Scenario 4)
% ADC doses	. . .[c]	36.05	88.61	. . .
ADC doses	. . .	2643	6497	7332
ADC line items	. . .	1891	4648	5246
% CF doses	. . .	63.95	11.39	. . .
CF doses	7332	4689	835	. . .
CF line items	3799	2413	433	. . .
Total doses	7332	7332	7332	7332
Total line items	3799	4304	5081	5246
Census	376	376	376	376
BCF line items	. . .	212	316	338
NV line items	. . .	63	94	100
Carousel line items	. . .	149	222	238
Patient care units	25	25	25	25
ADCs	. . .	29	40	40
Probability of missing dose, %	1.39	1.01	0.45	0.32
Time spent on missing dose, min:sec	01:17.8	00:55.7	00:27.3	00:25.9
Probability of queuing for ADC, %	. . .	3.18	7.20	8.22
Time spent queuing for ADC, min:sec	. . .	00:35.8	01:54.0	02:09.6

[a]ADC = automated dispensing cabinet, UWHC = University of Wisconsin Hospital and Clinics, IUHB = Indiana University Health—Bloomington, CF = cart fill, BCF = batch cabinet fill, NV = narcotic vault.
[b]All data are no. unless specified otherwise.
[c]Not applicable.

pitals' different methods of dispensing insulin products (floor stock vials versus patient-specific pen injectors).

The workload statistics data indicated that 88.61% of medication doses were dispensed from ADCs at IUHB. The number of ADC pockets restocked per day, as a percentage of the number of medication doses administered per day, was 0.043 pocket per dose.

At the time of the study, IUHB's inpatient units were served by 16 large main ADCs, 13 large auxiliary cabinets, and 19 ADC towers. Additionally, the dollar values (based on the UWHC acquisition cost) of the inventory contained within a cabinet on a critical care unit was assessed; the cost for UWHC to stock a critical care cart similarly to IUHB was found to be $5800.

Simulations of a decentralized medication distribution system at UWHC. The simulation results indicated that if UWHC were to transition to a medication dispensing system such as that in place at IUHB at the time of the study, the required pharmacy technician time would increase by about 211 minutes per day, pharmacist time would increase by about 11 minutes per day, and nurse time would increase by approximately 977 minutes per day. Data on daily human resource utilization under each simulation scenario are represented graphically in Figure 1, with the associated projected changes in total annual personnel opportunity cost shown in Figure 2.

One-way sensitivity analysis of the base-case medication dispensing model at UWHC indicated that the model was sensitive to four factors: the nurse time required to obtain medication doses from cassette drawers and ADCs, the nurse time required to manipulate a dose requiring additional preparation, the inpatient census, and the probability of additional manipulation being required to prepare a dose for administration.

Table 6.
Comparative Human Resource Times and Cost Differentials[a]

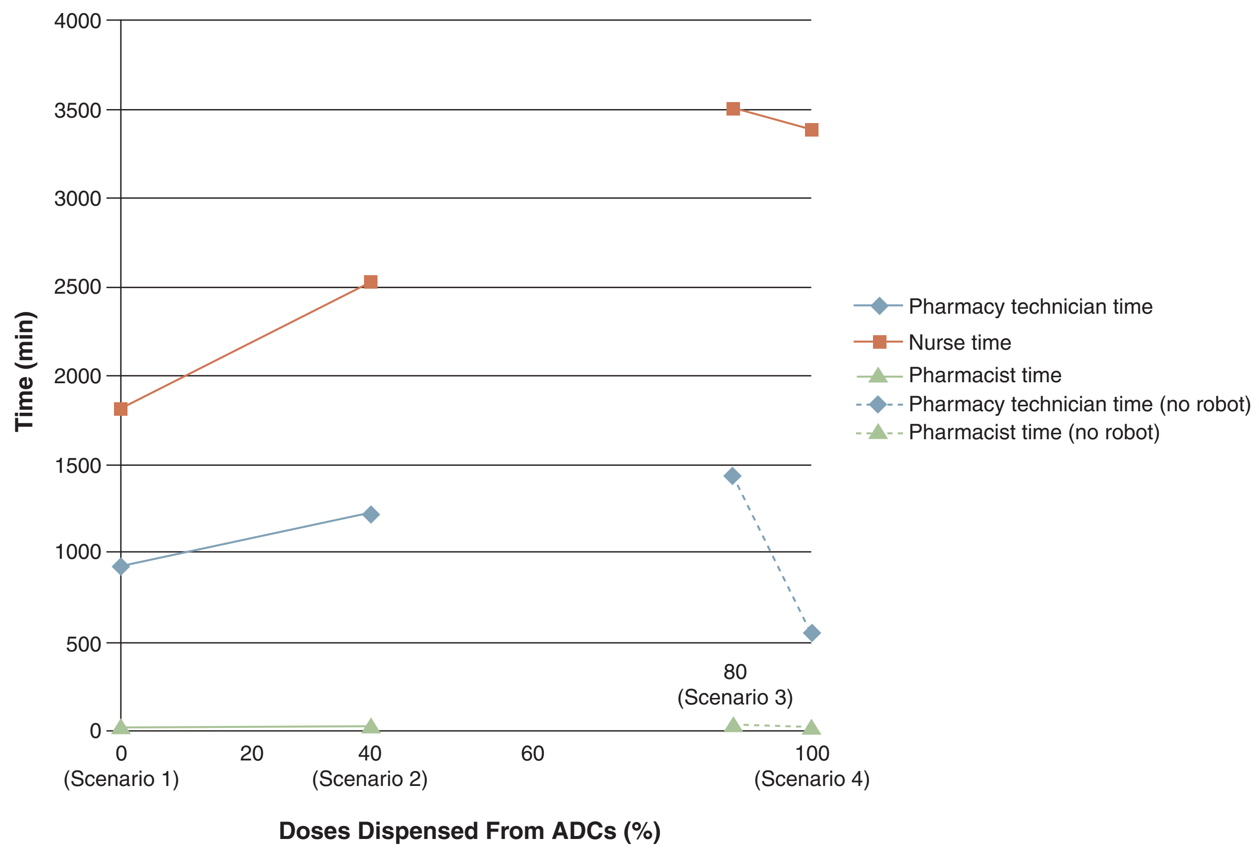
Variable	No ADCs (Scenario 1)	Hybrid (Scenario 2)	Decentralized (Scenario 3)	No CF (Scenario 4)
	Medication Distribution Scenario			
Human resource time, by role, min				
ADC technician	. . .[b]	276.59	405.16	427.14
Narcotic technician	. . .	26.90	40.14	42.70
Carousel technician	. . .	52.90	78.81	84.49
Pharmacist	17.49	28.11	39.19	24.84
Decentralized technician	605	605	605	. . .
Nurse	1,817.50	2,524.09	3,501.25	3,383.30
Cart-fill technician	215.69	176.84	202.75	. . .
Robot	537.08	359.58	. . .	. . .
TCT technician	93.00	66.94	84.33	. . .
CUD technician	20.51	20.53	20.53	. . .
Aggregated human resource time, min				
Pharmacy technician	934.20	1,225.70	1,436.72	554.33
Pharmacist	17.49	28.11	39.19	24.84
Nurse	1,817.50	2,524.09	3,501.25	3,383.30
Total pharmacy	951.69	1,253.81	1,475.91	579.17
Total nursing	1,817.50	2,524.09	3,501.25	3,383.30
Combined total	2,769.19	3,777.90	4,977.16	3,962.47
Change in human resource time relative to base case (hybrid model), min				
Pharmacy technician time	–291.50	. . .	211.02	–671.37
Pharmacist time	–10.62	. . .	11.08	–3.27
Nurse time	–706.59	. . .	977.16	859.21
Cost differential relative to base case (hybrid model), $U.S.				
Daily personnel cost	–489.54	. . .	629.29	343.39
Yearly personnel cost	178,680.59	. . .	229,691.42	125,338.25

[a]ADC = automated dispensing cabinet, CF = cart fill, TCT = tech-check-tech, CUD = central unit dose.
[b]Not applicable.

An additional alternative scenario was developed and simulated in order to project the likely impact on the overall skill mix if pharmacy technicians were to assume an increased role in obtaining medications for nurses. In this scenario, it was assumed that pharmacy technicians would be responsible for obtaining (from ADCs and cassette drawers) all doses to be administered to patients. This scenario could represent a medication dispensing system in which medications are picked as part of a cart fill and stored in ADCs, with technicians permitted to obtain the medications from those locations and place them in a nurse server at the patient's bedside. Analysis of this scenario revealed that the nursing time required per day would decrease by 1724.64 minutes (5.04 full-time equivalent [FTE] nurse resource units) and the pharmacy technician time required would increase by 1783.62 minutes per day (5.22 FTE units); based on the median hourly wage for nurses and pharmacy technicians at the time of the study, the projected reduction in nurse labor and increase in pharmacy technician labor would have resulted in a total annual cost savings of $217,000.

Based on the bed-to-cabinet ratios at IUHB and the existing ratios at UWHC, it was estimated that UWHC would need to invest in 14 large main ADC cabinets, 14 auxiliary cabinets, and 40 towers to transition to a medication dispensing system similar to the IUHB system, which would have increased UWHC's ADC costs by more than 225%. Additionally, based on the relative acquisition costs of the medication inventory in cabinets at UWHC and at IUHB, there would be a significant increase in UWHC's on-hand medication inventory. For example, the acquisition cost of the medications stocked in a critical care unit at IUHB was more than quadruple that of the medications stocked in a critical care unit at UWHC at the time of the study ($5800 and $1309, respectively); therefore, in a scenario involving UWHC's transition to stocking ADCs in critical care areas (as observed at IUHB), the cost of the medications stocked in those cabinets would be expected to increase. Similarly, we believe that the acquisition cost of the medications stocked in non-critical-care units would

Figure 1. Projected changes in daily human resource utilization, as a function of the percentage of doses dispensed from automated dispensing cabinets (ADCs), under the four simulated scenarios: exclusive use of cart fill with no ADCs (scenario 1), the base case (scenario 2), a decentralized system like that of the comparator institution (scenario 3), and exclusive use of ADCs with no cart fills (scenario 4).



most certainly be higher at IUHB, with the magnitude of the differences varying by type of unit.

The overall estimated costs of a transition from a hybrid to a decentralized medication distribution system are reported in Table 7. It was calculated that if UWHC were to transition to a decentralized medication system, the increase in human resource time to dispense and obtain medications would equate to an annual human resource opportunity cost of $229,691.

The impact of such a transition on medication inventory costs is reported as the cost per inventory turn. For a hybrid medication distribution system, the cost per inventory turn includes the inventory maintained in ADCs as well as the online and off-line inventories maintained in the central dispensing robot; for a decentralized system, it includes the medication inventory maintained in ADCs. The costs per inventory turn in the modeled hybrid and decentralized systems were calculated at $129,316 and $187,691, respectively. Thus, it was calculated that if UWHC were to adopt a decentralized medication distribution system, the department's annual drug expense would increase by $58,375 per inventory turn. In addition, the medication dispensing technology necessary to support a decentralized medication distribution is more costly than that used in a hybrid system (our study indicated estimated annual costs of $624,638 and $385,635, respectively). This cost differential relates to the long useful life of the dispensing robot used to perform cart fills, which allows the cost of the technology to be spread over several years.

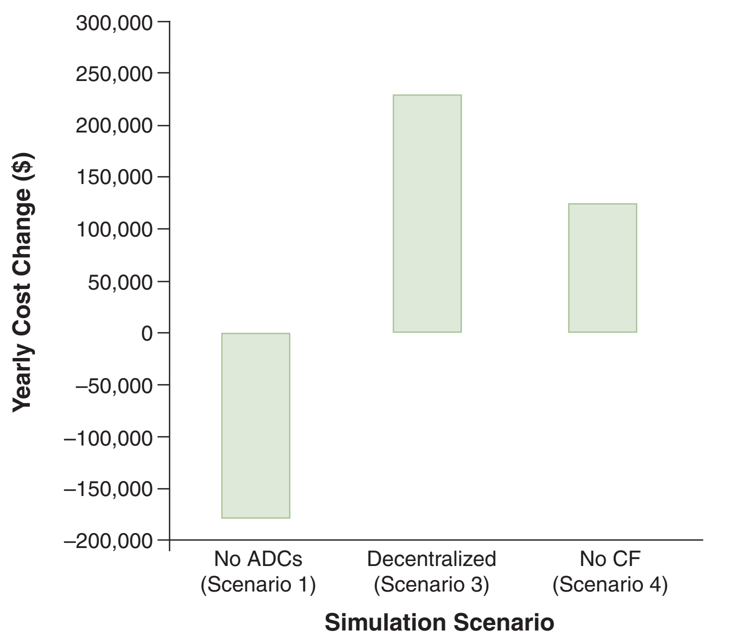
Discussion

Simulation of the existing and potential alternative medication dispensing systems at UWHC revealed that the existing system compared favorably with the others with respect to total human resource utilization and employee skill mix. The simulations indicated that under the existing hybrid medication distribution system, 1225.7 minutes of technician time per day was dedicated to performing the medication cart fill and maintaining ADC inventories. Pharmacists were spending 28.11 minutes per day validating the work performed by pharmacy technicians in performing the 24-hour cart fill and the batch cabinet fill. The pharmacist time supporting this portion of the medication dispensing system at UWHC was very low due to the implementation of a board of pharmacy-approved "tech-check-tech" program. Under this program, pharmacists did not have to check any doses picked by the centralized dispensing robot and only needed to perform a 15% quality-assurance check of medications picked by a pharmacy technician and checked by another pharmacy technician.

Simulation modeling indicated that the nurse time dedicated to obtaining medications and preparing them for administration within the existing hybrid system was 2524.09 minutes per day; it is important to note that this represented only a portion of the nurse's role in the medication-use process. In the scenario of a transition to a decentralized medication distribution system such as that observed at IUHB, the total human resource workload would have increased from 3777.9 to 4977.16 minutes per day.

The simulation data indicated that only one alternative medication distribution system—the system utilizing no ADCs—would have resulted in reduced human resource time requirements (because it takes much longer to obtain a dose from an ADC compared with a cassette drawer). The finding that nurse time within a no-ADC system would decrease

Figure 2. Estimated changes in total annual personnel opportunity cost if University of Wisconsin Hospitals and Clinics were to transition from a hybrid medication distribution model to one of the three simulated alternative dispensing models: exclusive use of cart fill (no ADCs), decentralized distribution as implemented at Indiana University Health—Bloomington at the time of the study (decentralized), and no use of cart fill (no CF). ADC = automated dispensing cabinet, CF = cart fill.



by 706 minutes per day was likely overstated. In fact, nursing time may actually increase in such a system because nurses are required to perform manual reconciliation of controlled-substance utilization.

Our simulations indicated that as the percentage of doses dispensed from ADCs increases, the nurse time dedicated to obtaining and preparing doses for administration increases up to and including the case in which 88.61% of doses are dispensed from ADCs (as observed at IUHB). Nursing time then decreases slightly (from 3501.25 to 3383.3 minutes per day) in the scenario in which all doses are dispensed from ADCs. This modest decrease is due to the reduction in time spent searching for missing doses as well as the complete elimination of the cart-fill workflows (obtaining cart-fill doses and preparing those doses for administration).

The scenario in which there is no cart fill may underestimate the technician labor that is necessary to support such a system. In an exclusively ADC-based system, it is likely that technician resources would be dedicated to loading and unloading ADC pockets based on patient orders. This workflow was not modeled because neither IUHB nor UWHC routinely practiced loading or unloading of ADC pockets based on patient orders. Consequently, data were not available to accurately model that workflow.

Additionally, our analyses indicated that within a decentralized medication distribution system in which more than 50% of doses are obtained from ADCs, the overall pharmacy time dedicated to medication distribution decreases as the percentage of doses dispensed from ADCs increases; in that respect, the study results corroborated those of Baker and colleagues.[11] However, the shift of work from pharmacy technicians to nurses that is observed with greater decentralization represents an unfavorable change in skill mix to the organization, as nurses are a higher-cost resource than pharmacy technicians.

While the study results indicated that with its existing medication distribution system, UWHC was well positioned with respect to skill mix, it might be worthwhile to consider that there are other duties that pharmacy technicians might perform instead of nurses. As mentioned above, if pharmacy technicians assumed responsibility for obtaining all medication doses from ADCs and cassette drawers and preparing all doses for administration by nurses within UWHC's existing medication distribution system, nursing FTEs could be reduced, with a corresponding increase in pharmacy technician FTEs; this could yield dramatic labor cost savings for the organization and possibly a safer and more efficient medication-use system. Exploring pharmacy technicians' role in medication distribution to the bedside has been identified as an area of future study for our organization.

Limitations

There are limitations that must be considered in the context of this study. While the cart-fill process represents a mechanism solely for the replenishment of maintenance doses, restocking and obtaining doses from ADCs affect and are affected by both maintenance-dose and first-dose order fulfillment. As the percentage of doses dispensed from ADCs increases, there are varying effects on pharmacy and nursing workloads. In the analysis described here, the pharmacy labor required to support a highly decentralized

Table 7.
Comparative and Differential Estimated Annual Costs ($U.S.) of Hybrid and Decentralized Distribution Models[a]

Expense Category	Hybrid Model	Decentralized Model	Cost Differential
Annual personnel opportunity cost			
Nurse	537,727.93	745,900.46	208,172.54
Pharmacist	9,454.73	13,181.46	3,726.73
Pharmacy technician	103,344.90	121,137.05	17,792.15
Total	650,527.56	880,218.97	229,691.42
Annual technology costs			
ADC lease	270,709.00	595,681.80	324,972.80
Medication carousels[b]	28,956.58	28,956.58	. . .[c]
Robot[b]	85,969.54	. . .	–85,969.54
Total	385,635.12	624,638.38	239,003.26
Annual medication cost per ADC inventory turn[d]	129,316.18	187,690.97	58,374.79

[a]ADC = automated dispensing cabinet.
[b]Based on equipment contract price and projected useful life of 10 years.
[c]Not applicable.
[d]This value reflects on-hand inventory in ADCs (and the dispensing robot in a hybrid system) and represents the cost to turn the pharmacy inventory once.

distribution system may have been overestimated because the shift from centralized to decentralized first-dose fulfillment was not modeled. However, the nursing workload in a highly decentralized model increased dramatically—much more than the pharmacy workload.

Conversely, it is likely that the nursing workload in a decentralized model was underestimated. The decentralized medication distribution system transfers traditional pharmacy technician roles to nurses. As a result, it is likely that the frequency of nurses arriving at the patient's bedside with the wrong medication or having forgotten to obtain a medication due for administration would be increased. Ultimately, this may result in increased foot traffic from the patient's room to the ADC. This potential impact on nursing workload (and workflows) was not modeled in our study.

Additionally, it was assumed that the relationships of the percentage of doses dispensed from ADCs and the frequency of ADC queuing, the time spent queuing for ADC access, the frequency of missing doses, and the time spent looking for missing doses were linear; this was done in order to estimate those parameters for simulation scenarios based on the percentage of doses dispensed from ADCs. These assumptions were made in order to "handicap" various medication distribution systems based on perceived advantages and disadvantages related to ADC queuing and missing doses. A similar assumption was made with regard to the number of ADC pockets restocked per dose administered. These relationships may, in fact, not be linear; therefore, this analytical assumption could have caused estimated human resource time for one or more scenarios to be inaccurate. While this is a methodological limitation, we believe the impact of assuming these linear relationships on the overall results of this study is minimal. The one-way sensitivity analysis revealed that the simulation model was insensitive to changes in the nurse time spent looking for missing doses, the frequency of queuing for ADC access, and the probability of a missing dose, which indicated that the values used to model those parameters did not substantially impact the output of the model.

This study did not assess nurse accuracy in obtaining medications from ADCs versus cassette drawers, nor did it assess other patient safety considerations. At an institution that does not use bedside bar-coding of patients and medications, it is possible that using a decentralized distribution system with ADCs (fitted with locked lidded drawers) would prevent medication errors that a hybrid medication distribution system would not prevent. While the patient safety implications of competing medication distribution systems represent an intriguing topic of study (and one that we intend to study in the future), it was beyond the scope of this investigation.

This study also did not assess the difference in medication turnaround time between the decentralized and hybrid medication distribution systems. It is very likely that medication turnaround time will be faster in a decentralized cabinet-based system, which may have a positive impact on nurse and patient satisfaction. However, it should be considered that not every medication ordered is needed immediately; many doses are not needed until 60–120 minutes (or longer) after the time of order verification. In those cases, the faster turnaround time attainable with a decentralized system is of negligible significance.

Estimates of the costs associated with transitioning from a hybrid to a decentralized medication distribution system were based on data snapshots of practices at UWHC and IUHB and did not consider confounding variables such as differences in practice, patient acuity, and medication formularies between the two institutions. If the pharmacy department at UWHC were to reconsider making such a transition, a more robust assessment of the required automation and technology, medication inventory, and physical plant enhancements would need to be completed.

Future areas for study could include a full analysis of the skill mix required to maintain medications at the patient's bedside, an assessment of pharmacy accuracy in filling and nurse accuracy in obtaining medications from various storage locations, and further exploration of the relationships of the percentage of doses dispensed from ADCs and the frequency of ADC queuing, the time spent queuing for ADC access, the frequency of missing doses, and the time spent looking for missing doses.

Conclusion

Based on the simulation results, it was decided that a transition from the existing hybrid medication distribution system to a more ADC-dependent model would result in an unfavorable shift in staff skill mix and corresponding human resource costs at the medical center.

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