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Original Research

Cost-effectiveness analysis of a unit dose dispensing robot in Thailand

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Abstract
Background: Medication errors can lead to serious consequences, including adverse drug events and even death. To reduce medication errors, many hospitals have implemented medication-dispensing technologies, including the Unit Dose Dispensing Robot (UDRs). However, no studies in Thailand have evaluated the costs and medication errors associated with UDRs. **Objective:** To conduct a cost-effectiveness analysis of the adoption of UDRs in comparison to traditional manual dispensing methods, focusing on costs and the reduction of medication errors. **Method:** Cost and medication error data were obtained from the database of a tertiary hospital in Thailand between 2017 and 2022. Medication errors were measured as the difference in error occurrence before and after UDR implementation. Cost components included labor costs, material costs, and the capital cost of UDRs. The incremental cost-effectiveness ratio (ICER) was calculated as the incremental cost per avoided medication error. One-way sensitivity analysis was performed to assess the impact of uncertainty in individual parameters on the results. **Results:** UDR implementation reduced wrong-drug, wrong-dose, and medication mix-up errors by 201, 62, and 6.33 events, respectively. Overall, UDRs prevented 269.34 medication errors annually at an incremental cost of 64,883.10 United States Dollars (USD), resulting in an ICER of 240.90 USD per avoided medication error. One-way sensitivity analysis indicated that the cost of medications after implementing the UDRs had the greatest influence on ICER variability, while labor costs after UDR implementation had the least impact. **Conclusions:** Implementing UDRs resulted in higher initial costs due to investments in infrastructure, technology, and labor; however, it significantly reduced medication errors. This evidence can be utilized to inform decision-makers in investing in automatic drug dispensers, promoting patient safety and increasing the efficiency of hospital medication dispensing systems in Thailand.

Keywords: cost-effectiveness analysis, unit dose dispensing robot, medication errors

INTRODUCTION

Medication errors are defined as any preventable events that could lead to inappropriate medication use or patient harm while the medication is being handled by healthcare professionals, patients, or consumers. Medication errors can occur at various stages of healthcare delivery, including prescribing, communicating orders, labeling, mixing, dispensing, packaging, distributing, product naming, administering medications, educating, monitoring, and overall medication use [1].

Medication errors are common and represent a significant global health concern. The U.S. Food and Drug Administration (FDA) reports more than 100,000 medication error cases annually[2]. Additionally, the World Health Organization (WHO) estimates that medication errors account for approximately 1% of total global healthcare expenditure[3]. In Thailand, the burden of medication errors is also notable. A study conducted at Buriram Hospital reported that medication errors represent approximately 96.97% of the risk of drug-related mistakes[4]. Furthermore, a study at Sriboonruang Hospital in 2022 found that medication errors in the inpatient department (IPD) occurred at a rate of 3.46 events per 1,000 prescriptions, totaling 403 incidents[5]. Similarly, Lampang Cancer Hospital reported a notably high pre-administration medication error rate of 54.5%[6]. These medication errors can result in serious consequences, including adverse drug events (ADEs) that may worsen the patient's condition, cause disease recurrence, or, in severe cases, lead to death. These errors also impose significant burdens on patients' families through increased healthcare costs and emotional distress. Moreover, healthcare professionals involved in medication errors may face legal and professional repercussions. Therefore, reducing medication errors is critical to improving patient safety and minimizing avoidable harm.

In response to this challenge, hospitals in many countries have

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adopted innovative medication-dispensing technologies, such as Automatic Dispensing Machines (ADMs), which package medications and medical supplies into patient-specific dose units. Among the various systems available, this study focuses specifically on the use of Unit Dose Dispensing Robots (UDRs). The UDRs accurately dispense patient-specific medications into a designated dose bag at prescribed administration times. In practice, the UDRs deliver all medications that a patient is required to take at a specific mealtime into a single-dose bag. The system stores prescription information and dispenses medications according to pre-programmed schedules. Each dose bag can be printed with customizable information, including the patient's name, medication name, administration instructions, barcode or QR code, ward, and other relevant details. UDRs are particularly well-suited for inpatient use, as they help ensure that patients receive their prescribed medications at the correct times in accordance with physicians' orders. The use of UDRs in hospitals offers several advantages, particularly in reducing the time required for medication dispensing and administration. UDRs can rapidly prepare medications into dose bags according to pre-set programming, thereby decreasing the workload of healthcare staff involved in medication preparation and administration. This allows medical personnel to allocate more time to other clinical responsibilities. In addition, because UDRs minimize reliance on manual processes, their use can reduce the likelihood of medication errors associated with human factors[7].

Numerous studies have demonstrated that ADMs can significantly reduce medication errors compared with traditional pharmacist-led dispensing processes[8,9,10,11]. One study evaluating the cost-effectiveness of a centralized automated unit dose dispensing system combined with barcode-assisted medication administration in a hospital setting reported a reduction in ADEs. However, the intervention was also associated with increased capital costs, resulting in a cost-effectiveness ratio of 17.69 Euro per avoided medication administration error[12]. In Thailand, a cost analysis study reported that the implementation of Automated Dispensing Systems led to an increase in total costs of approximately 1,849,624 United States Dollars (USD)[13].

To our knowledge, no study has specifically evaluated both the costs and medication error outcomes associated with the use of UDRs in the Thai healthcare setting. Therefore, the objective of this study was to conduct a cost-effectiveness analysis of adopting UDRs compared with traditional manual dispensing methods, focusing on costs and medication error reduction.

METHOD

Study design

A cost-effectiveness analysis was performed to compare drug dispensing using UDRs with traditional manual dispensing methods. Both cost and outcome data were retrieved from the electronic database at Nopparat Rajathanee Hospital, a tertiary care institution under the Department of Medical Services, Ministry of Public Health, in Bangkok, Thailand. The cost included labor, material, capital and overhead costs, while the outcome was measured in terms of the total number of avoided medication errors. The Incremental Cost-Effectiveness Ratio (ICER) was calculated to assess the value of the UDRs compared to manual dispensing. Cost data were retrospectively collected from January 2017 to December 2019 (pre-intervention period), and from January 2020 to December 2022 (post-intervention period). The information on drug dispensing and medication errors is kept confidential and stored within the National Reporting and Learning System (NRLS), a platform for reporting and analyzing safety incidents. Additionally, this data was housed in the Healthcare Risk Management System on Cloud (HRMS on Cloud) Version 5.0-5.5, a Hospital Risk Management Information System maintained by the Healthcare Accreditation Institute (HAI), a Public Organization. Access to this data was limited based on the individual's role and position within the hospital.

The study received approval from the Institutional Review Board at Nopparat Rajathanee Hospital (No. 18/2567). It was conducted in accordance with the ethical guidelines outlined in the Declaration of Helsinki and the Principles of the Belmont Report.

Study setting

Traditional manual dispensing method

The hospital's database management was handled by the PMK software application (version 22), operating on Windows XP, with all systems connected via a LAN. Medications were managed by the pharmacy inventory unit, categorized into types such as topical medications, tablets, injectables, liquid medications, saline solutions, and temperature-sensitive medications (stored in refrigerators). The medication dispensing process was split into outpatient and inpatient services, each with its own sub-pharmacy that organized and stored medications by type. The pharmacy staff were responsible for arranging medications, and pharmacists carefully reviewed all medications before dispensing them to patients or sending them to inpatient wards.

UDRs

UDR implementation started in January 2020. UDRs utilized barcode and RFID systems to ensure accurate medication refilling and to track canister locations. The device had an 8-inch Touch Screen Color LCD for operation controls and a Photo Sensor for pill count verification. It selected, counted, and packed medications into labeled bags. The system was integrated with the hospital information system (HIS) and could operate in stand-alone mode. UDRs dispensed 50 bags per minute and provided audio/text alerts for various issues. The system verified medication types and containers during refilling, generated reports on inventory levels and patient-specific dispensing, and alerted users when stock levels were low. In addition, UDRs automatically generated daily refill reports for pharmacists. When a patient in the ward required ongoing medication, the nurse forwarded the physician's order to the pharmacy. A pharmacy assistant recorded the order in the PMK program and calculated the associated costs.

The pharmacist then verified the accuracy of the medications prepared by the assistant before dispensing. For subsequent medication orders, the UDR automatically organized the medications, with the pharmacist responsible for verifying the accuracy of the dispensed items. Medication organization by the UDR was performed using data from each patient's electronic database. Two dispensing rounds were scheduled daily: one in the morning at 8:00 AM and another in the evening at 7:00 PM. Each sachet was labeled with patient-specific information, including the patient's name, treating department, medication name and strength, administration date and time, barcode, hospital number (HN), and admission number (AN). The proportion of medications dispensed using UDRs accounted for 88.95% of total hospital dispensing in 2020, 85.57% in 2021, and 90.15% in 2022.

Data collection

Measurement of costs

The cost collection in this study was divided into two categories: direct costs and indirect costs. The costs for each year were adjusted using the consumer price index. All expenses were converted from Thai Baht (THB) to United States Dollars (USD) using the average exchange rate from the Bank of Thailand as of 2024, which is 35.97 THB per USD. The details of the cost calculation for each category are as follows:

Direct costs

Labor costs

Labor costs referred to expenses associated with positions involved in the inpatient drug-dispensing process, including pharmacists, pharmacist assistants, and pharmacist technicians. These costs were divided into two components: salaries and overtime pay.

The monthly salary cost for pharmacists was calculated by dividing the starting salary by the total monthly working hours, then multiplying the result by the hours spent on drug dispensing per month. Pharmacists worked 3 hours per day dedicated to drug dispensing. For pharmacy assistants and technicians, salary costs were calculated using the same method. The total salary cost for each position was summed to determine the annual labor cost for inpatient drug dispensing. Salary calculations were performed separately for each year based on the applicable salary rates.

From 2017 to 2019, pharmacists were exclusively responsible for handling the drug dispensing process. However, with the introduction of meal-specific automated drug dispensing machines between 2020 and 2022, the working time for all staff positions was reduced by 1 hour per day, resulting in 2 hours per day dedicated to the process.

Overtime costs for pharmacists were calculated by multiplying the hourly overtime rate by the total overtime hours worked during day and night shifts per month. Pharmacists working day shifts and night shifts accrued 3 and 4 hours of overtime per day over 10 and 30 days per month, respectively. The overtime costs for pharmacy assistants and technicians are calculated similarly. The annual overtime cost for each position is then determined by summing the monthly totals and adjusting for each year based on the respective salary rates from 2017 to 2022.

Material cost

Material costs included all expenses related to the drug-dispensing process, encompassing both sachets and medications. The cost of sachets was calculated by multiplying the total number of sachets used by the unit price per sachet. Similarly, medication costs were estimated by multiplying the quantity of each medication dispensed by its corresponding unit price.

Capital cost

For drug dispensing using UDRs and pharmacist involvement, the capital cost included initial expenses for installing UDRs and their software, as well as ongoing maintenance costs after implementation. Calibration expenses were not included as they were the responsibility of the UDR's company. The total capital expenditure was calculated by aggregating all costs incurred annually from 2020 to 2022.

Indirect costs

Indirect costs encompassed expenses incurred from various units within Nopparat Rajathanee Hospital, including water and electricity, as well as non-income-generating units such as administration, management, purchasing, storage, and academic departments. In this study, overhead indirect costs were estimated at approximately 20% of the direct costs.

Measurement of outcomes

Study outcomes were evaluated by recording pre-dispensing medication errors identified by pharmacists prior to medication delivery to patients. These errors were categorized into three types: (1) wrong drug, where the dispensed medication did not correspond to the prescription; (2) wrong dose, where the dispensed dose was higher or lower than prescribed; and (3) mixed-up medications, where medications were incorrectly placed into the wrong sachets.

Economic evaluation

The incremental cost-effectiveness ratio (ICER) was calculated by dividing the incremental cost associated with integrating UDRs into the dispensing process by the difference in the annual number of avoidable medication errors.

The one-way sensitivity analysis assessed the impact of changes in individual parameters, including labor costs, drug costs, medication pouch costs, and the number of medication error events. The results were presented using a tornado diagram, which displays the range of ICERs ordered from the most to the least influential parameters based on their variability.

RESULTS

Effect of UDRs

The traditional manual dispensing methods resulted in 451, 488, and 455 medication errors in 2017, 2018, and 2019, respectively, as shown in Table 1. After the adoption of UDRs alongside pharmacists, the number of errors decreased to 229 in 2020, 155 in 2021, and 202 in 2022. This reflected a reduction in the average annual number of medication errors from 464.67 to 195.33 events. As a result, the use of UDRs helped prevent approximately 269.34 medication errors per year, as presented in Table 2.

The cost of UDRs

The definitions of practices prior to and after the implementation of the UDRs within the medication dispensing process were presented in Table 3. Following the implementation of the UDRs, the total cost, including overhead, increased by 64,883.10 USD annually. Further details were illustrated in Table 4.

Cost-effectiveness analysis

The comparison of costs, medication errors, and the ICER before and after the implementation of UDRs is shown in Table 5. The total annual cost increased from 184,584.38 USD without UDRs to 249,467.47 USD with UDR implementation, resulting in an incremental cost of 64,883.10 USD per year. The annual number of medication errors decreased from 464.67 events before implementation to 195.33 events after implementation, corresponding to 269.34 avoidable medication errors. Based on these results, the ICER was estimated at 240.90 USD per avoided medication error.

Table 1. Annual number of medication errors by type without UDRs and with UDRs

Type of medication errors	Annual medication errors without UDRs			Annual medication errors with UDRs		
	Year 2017	Year 2018	Year 2019	Year 2020	Year 2021	Year 2022
Wrong drug	316	342	329	135	99	150
Wrong dose	124	141	120	93	56	50
Medication mix-up	11	5	6	1	0	2
All medication errors	451	488	455	229	155	202

UDRs; Unit Dose Dispensing Robots

Table 2. Frequency of medication errors by type with and without UDRs and the number of avoided medication errors.

Type of medication errors	The average number of medication errors without UDRs per year (%)	The average number of medication errors with UDRs per year (%)	The number of avoided medication errors (%)
Wrong drug	329.00 (70.80%)	128.00 (65.53%)	201.00 (74.63%)
Wrong dose	128.33 (27.62%)	66.33 (33.96%)	62.00 (23.02%)
Medication mix-up	7.33 (1.58%)	1.00 (0.51%)	6.33 (2.35%)
All medication errors	464.67	195.33	269.34

UDRs; Unit Dose Dispensing Robots

Table 3. Operational definition of medication dispensing without UDRs and with UDRs, based on an incremental costing approach.

Resource type	Resource for medication dispensing by pharmacists alone	Resources for medication dispensing using UDRs
Labor cost		
- Pharmacist salary	Medication-related tasks were performed during regular working hours.	
- Pharmacist Technician salary		
- Pharmacist Assistant salary		
- OT Pharmacist salary	Medication-related tasks were performed during nonstandard working hours, including both day and night shifts.	
- OT Pharmacist Technician salary		
- OT Pharmacist Assistant salary		
Material cost		
- Medicine package cost	The cost of medication packets was categorized by medication type for each inpatient.	
- Medication cost	The medication costs for inpatients.	
Capital cost		
- UDRs	-	Investment cost for the entire automatic medicine dispenser and software installation cost.
- Maintenance cost	-	Maintenance costs of automatic medicine dispensers

UDRs; Unit Dose Dispensing Robots, OT; Overtime

Table 4. Annual cost without UDRs and with UDRs.

Cost Type		Cost without UDRs (USD)	Cost with UDRs (USD)	Difference cost (USD)
1.1 Labor cost	Pharmacist salary	2,891.27	2,114.22	-777.05
	Pharmacist Technician salary	1,923.66	1,379.52	-544.14
	Pharmacist Assistant salary	1,375.10	952.83	-422.27
	Total salary	6,190.02	4,446.56	-1,743.46
	OT Pharmacist salary	6,797.97	6,176.07	-621.9
	OT Pharmacist Technician salary	4,078.78	3,705.64	-373.14
	OT Pharmacist Assistant salary	3,059.08	2,779.23	-279.85
	Total OT	13,935.83	12,660.94	-1,274.89
1.2 Material cost	Medicine package cost	5,267.98	16,290.15	11,022.17
	Medication cost	128,426.48	144,466.87	16,040.39
	Total Material cost	133,694.46	160,757.02	27,062.57
1.3 Capital cost	UDRs	-	27,800.95	27,800.95
	Maintenance cost	-	2,224.08	2,224.08
	Total capital cost	-	30,025.03	30,025.03
Total cost (excluding overhead cost)		153,820.31	207,889.56	54,069.25
Overhead cost 20%		30,764.07	41,577.91	10,813.85
Total cost		184,584.38	249,467.47	64,883.10

UDRs; Unit Dose Dispensing Robots, OT; Overtime, USD; United States Dollar

Table 5. The frequency of annual medication errors, costs, and incremental cost-effectiveness ratio of implementing UDRs.

	Cost (USD)	The average number of medication errors per year	Incremental cost per avoided medication error (USD)
Without UDRs	184,584.38	464.67	240.9
With UDRs	249,467.47	195.33	
Incremental comparison	64,883.10	269.34	

UDRs; Unit Dose Dispensing Robots, USD; United States Dollar

Sensitivity analysis

The results of the one-way sensitivity analysis, illustrated in the tornado diagram (Figure 1), indicated that the cost of medications after implementing the UDRs was the parameter with the greatest impact on the ICER. Variation in this parameter resulted in the highest ICER, reaching 18,116.41 USD per avoided medication error. The second most influential parameter was the medication cost prior to UDRs implementation, followed by the number of avoided medication errors related to incorrect drug type and incorrect dosage. In contrast, the labor cost of pharmacy technicians after UDRs implementation had the least influence on ICER variability. For this parameter, the ICER ranged narrowly from 240.85 USD to 240.99 USD per avoided medication error.

DISCUSSION

The implementation of UDRs in the dispensing process with a pharmacist added an extra cost of 64,883.10 USD annually and decreased medication errors by 269.34 cases. As a result, the ICER was 240.90 USD per avoided medication error. One-way sensitivity analysis further demonstrated that medication costs after UDR implementation were the most influential parameter affecting ICER variability.

An ICER of 240.90 USD per avoided medication error represented a cost-effective investment in enhancing patient safety. UDR implementation enabled the automated preparation of patient-specific single-dose sachets organized by scheduled administration times. This automation eliminated the need for manual sorting and preparing medications, as required in traditional dispensing systems, thereby reducing the risk of errors, particularly those related to medications with multiple strengths or look-alike and sound-alike names. In addition, UDR adoption improved hospital efficiency by reducing the time required for pharmacists, pharmacy technicians, and pharmacy assistants to perform dispensing-related tasks, leading to lower labor costs, especially in terms of working hours and overtime.

To our knowledge, this study is the first in Thailand to evaluate the costs associated with avoiding medication errors. Previous studies have primarily focused on clinical outcomes and consistently reported reductions in medication errors following the implementation of single-dose automated dispensing systems. These findings align with a systematic review demonstrating that the use of single-dose automated

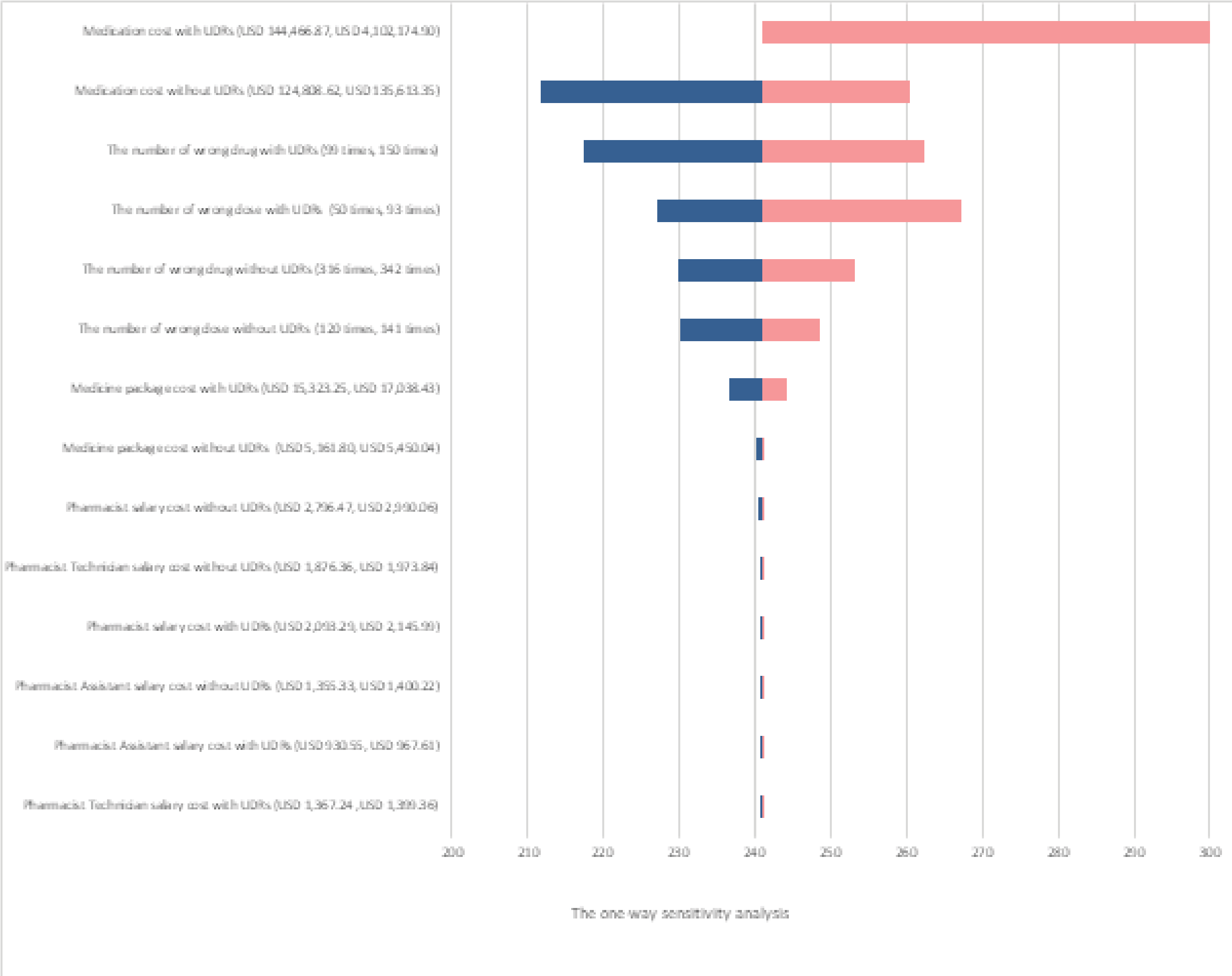

Figure 1. Tornado diagram
UDRs; Unit Dose Dispensing Robots, USD; United States Dollar, ICER; Incremental Cost-Effectiveness Ratio

dispensers combined with healthcare professional oversight significantly reduced medication errors compared with manual dispensing alone[9]. Similar results have been reported in studies from Taiwan, which showed a reduction in medication errors in intensive care units,[8] Denmark, where complex automated medication systems (cAMS) decreased medication errors,[10] and Austria, where automated dispensers reduced selection errors, preparation errors, incorrect dosage forms, wrong doses, and wrong medications[11]. Consistent with these studies, our findings indicated that single-dose automated dispensing systems reduced wrong-drug, wrong-dose, and medication mix-up errors.

Regarding costs, previous studies in Thailand comparing automated single-dose dispensing systems combined with pharmacist involvement to pharmacist-only dispensing reported increased total costs, consistent with our findings[13,14]. Despite higher initial and operational costs, cost-to-error reduction analyses have demonstrated favorable ratios, suggesting that investments in automated dispensing technology are justified when considering the substantial improvements in patient safety and reductions in medication errors. Overall, the benefits associated with fewer errors and improved dispensing outcomes appear to outweigh the additional costs. These findings provide useful evidence to support technology adoption and management decisions in Thai hospital settings.

At the hospital data collection site, informal qualitative feedback from pharmacy staff provided additional insights into the practical implementation of UDRs. Staff members generally expressed satisfaction with the system, noting its potential to enhance workflow efficiency and alleviate the burden of manual dispensing. However, several operational challenges were identified. These included the need for daily medication refills to maintain drug stability. Humidity required regular replacement of desiccants, and dust accumulation necessitated frequent cleaning to ensure hygiene and uninterrupted operation. Moreover, the system was unable to split tablets, requiring manual preparation of half-tablet doses prior to refilling.

This study has several limitations. First, medication costs increased substantially in 2021–2022 due to the COVID-19 pandemic, which led to higher patient admissions and increased medication use, including newly introduced drugs. Therefore, medication cost data from 2020 were used for the base-case analysis, while costs from 2021–2022 were explored through one-way sensitivity analyses to assess variability in results. Second, data were collected from a single center and were primarily verified by a single pharmacist at Nopparat Rajathanee Hospital, which may increase the risk of data inaccuracies. Third, medication error data were limited to wrong drug, wrong dose, and medication mix-up errors, while errors related to incomplete dispensing or incorrect quantities were not captured. Future studies incorporating a broader range of error types may provide more comprehensive insights. Finally, overhead costs were estimated rather than directly measured, as data collection was constrained by time and feasibility; thus, overhead costs were assumed to be 20% of total costs.

CONCLUSION

In conclusion, implementing UDRs resulted in higher initial costs due to investments in infrastructure, technology, and labor; however, it significantly reduced medication errors. This evidence can be utilized to inform decision-makers in investing in automatic drug dispensers, promoting patient safety and increasing the efficiency of hospital medication dispensing systems in Thailand.

AUTHORSHIP CONTRIBUTION

Vittanee Getupook- Conceptualization, Data curation, Resources, Writing – original draft

Supichaya Klubfang- Formal analysis, Writing – original draft

Monchaya Atthapak- Formal analysis, Writing – original draft

Attaya Plangsanguan- Data curation, Resources

Manchuporn Yomsiri- Data curation, Resources

Parnnaphat Luksameesate- Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Writing – review and editing

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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