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Original Article

Persistent Stock Discrepancies In Hospital Pharmacy Supply Chains: Why Robotics, System Integration, And Artificial Intelligence Have Not Closed The Reconciliation Gap

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ABSTRACT

Background: Hospital pharmacies have invested heavily in robotic dispensing, automated storage and retrieval systems (ASRS), automated dispensing cabinets (ADCs), enterprise resource planning (ERP) integration, and, increasingly, artificial intelligence (AI)-based demand forecasting and anomaly detection. Despite this, perpetual-inventory-to-physical-stock discrepancies continue to be reported across acute-care settings. Objective: This paper synthesizes evidence on the causes of residual stock discrepancy in automated and AI-augmented hospital pharmacy supply chains, and proposes a reconciliation framework that treats discrepancy as a systems-integration problem rather than a technology-adoption problem. Methods: A narrative review of peer-reviewed literature, health-system white papers, and vendor-reported case studies on pharmacy automation, radio-frequency identification (RFID), barcode workflows, and AI-enabled inventory analytics was conducted, supplemented by root-cause analysis using a socio-technical systems lens. Findings: Discrepancies persist for five interacting reasons: (1) physical–digital reconciliation gaps at the point of human handling (borrowing, waste, returns, and multi-step dispensing that automation does not fully observe); (2) line-of-sight and data-capture limits of barcode and even some RFID deployments; (3) data latency and fragmentation across ADC, ERP, electronic health record (EHR), and wholesaler systems that are "integrated" at the interface level but not at the transaction level; (4) AI forecasting and anomaly-detection models that are only as reliable as the transactional data they are trained on, and which can mask rather than resolve upstream data-quality defects; and (5) governance and process gaps, including inconsistent downtime procedures, override cultures, and unclear accountability for reconciliation. Case evidence from automated dispensing evaluations and RFID deployments shows measurable improvement in accuracy and time-to-restock, but not elimination of discrepancy. Conclusion: Technology adoption narrows but does not close the reconciliation gap. Sustained reduction in stock discrepancy requires pairing automation and AI with transaction-level data governance, closed-loop verification at every physical handoff, and explicit ownership of exception handling.

Keywords: hospital pharmacy; inventory discrepancy; pharmacy automation; robotic dispensing; radio-frequency identification (RFID); artificial intelligence; supply chain integration; medication safety.

INTRODUCTION

Medication inventory sits at the intersection of patient safety, regulatory compliance, and capital efficiency. Pharmaceutical and medical-surgical supplies routinely represent close to ten percent of an acute-care hospital's operating budget, and unmonitored or mismanaged inventory can hide millions of dollars of untracked stock within a single facility while simultaneously generating stockouts that interrupt care.

Over the past two decades, hospital pharmacies have progressively layered automation onto medication distribution: automated dispensing cabinets (ADCs) at the point of care, robotic dispensing and automated storage and retrieval systems (ASRS) in central pharmacy, barcode-based verification, and, more recently, radio-frequency identification (RFID) tagging and AI-driven demand forecasting and anomaly detection. Enterprise integration efforts have attempted to connect these systems to the electronic health record (EHR), the pharmacy information system, and hospital ERP/procurement platforms,

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with the stated goal of a single, trustworthy, real-time inventory record.

Yet operational reports and published evaluations continue to describe a persistent gap between what the system of record says is on hand and what is physically present — a gap that shows up as expired stock discovered on shelves, emergency stockouts of items the system marks as available, and reconciliation variances that consume technician and pharmacist time during counts and audits. This paper asks a direct question: if robotics, tight system integration, and AI are all present, why do stock discrepancies in hold/transaction records still occur, and what would meaningfully close the gap rather than merely narrowing it?

2. METHODS

This paper follows a structured narrative-review approach, appropriate for synthesizing a cross-disciplinary evidence base (clinical pharmacy, health informatics, and industrial/supply-chain engineering) around a single applied question, rather than a formal systematic review with meta-analysis.

2.1 Search Strategy

Peer-reviewed literature was identified through PubMed/MEDLINE, Scopus, and Google Scholar using combinations of the terms: “hospital pharmacy”, “automated dispensing cabinet”, “inventory robot”, “drug distribution system”, “radio-frequency identification” OR “RFID”, “barcode medication”, “artificial intelligence” OR “machine learning”, “inventory discrepancy”, “medication reconciliation”, and “supply chain integration”, combined with Boolean AND/OR operators. The search was limited to English-language sources published between 2010 and 2026, with priority given to systematic reviews and prospective evaluations published from 2018 onward to capture the most current automation and AI deployments.

2.2 Inclusion and Exclusion Criteria

Sources were included if they (a) reported empirical outcomes (accuracy, time, cost, safety, or discrepancy rate) for automated, RFID-enabled, or AI-augmented hospital pharmacy inventory or dispensing systems, or (b) provided documented case-level detail on implementation outcomes in an acute-care or health-system pharmacy setting. Sources were excluded if they addressed outpatient retail pharmacy exclusively without transferable acute-care relevance, or if they were promotional material without any reported outcome data.

2.3 Source Composition and Screening

Seven peer-reviewed systematic reviews, prospective evaluations, and quasi-experimental studies met inclusion criteria and form the primary evidence base for Sections 3 and 5 (Ahtiainen et al., 2020; Batson et al., 2021; Fox et al., 2021; Rhodes, 2021; Zheng et al., 2021; Jumeau et al., 2021; Fong et al., 2022). These were supplemented by five industry-reported and health-system case accounts, used exclusively for illustrative, transparently labelled case material in Section 6 and not treated as peer-reviewed evidence. Screening, extraction, and synthesis were performed by a single reviewer; this is disclosed as a limitation in Section 9, consistent with a narrative rather than systematic review design.

2.4 Analytical Approach

Root causes (Section 5) were derived using a socio-technical systems lens, adapted from Sittig and Singh's (2010) model for studying health information technology in complex adaptive healthcare systems, which distinguishes technology-layer causes (sensor and interface limitations), data-layer causes (latency, fragmentation, model dependency), and organizational-layer causes (governance, ownership, override culture) rather than attributing discrepancy to any single automation component in isolation. This framing is used descriptively throughout Section 5 to classify each root cause by layer (Table 1) rather than as a formal test of the model itself.

3. LITERATURE REVIEW

3.1 Robotic and Automated Dispensing Systems

Systematic reviews of automation in hospital pharmacy dispensing report consistent gains in dispensing accuracy and, in centralized configurations, in staff time savings, alongside improved patient safety outcomes relative to fully manual workflows (Batson et al., 2021; Ahtiainen et al., 2020). At the same time, prospective evaluations

of combined ADC and inventory-robot deployments have found that while picking accuracy improves, total distribution time does not always fall, and restocking time for ADCs can increase significantly — automation downtime events force a reversion to manual procedures that reintroduce the very transcription and counting errors automation was meant to remove (Fox et al., 2021). Discrepancy specifically, rather than dispensing error broadly, has also been studied directly: a quasi-experimental evaluation of expanded ADC dispensing-cassette functionality found that functionality changes measurably reduced blind-count controlled-substance discrepancies, indicating that discrepancy rates are sensitive to configuration choices within a single automated platform rather than being a fixed property of automation itself (Rhodes, 2021). A systematic review of ADC, barcode medication administration, and closed-loop system impacts on controlled-medication work processes similarly found that while ADCs eliminated manual end-of-shift counts in several settings, discrepancy reports still required interdisciplinary investigation, and under-resourcing of that investigation step — not the automation itself — was repeatedly identified as the constraint on resolution (Zheng et al., 2021). A prospective observational comparison of ADC-equipped and traditional ward-stock wards likewise found fewer dispensing errors and interruptions under ADCs, but did not find that the technology eliminated preparation-time variability, reinforcing that automation shifts rather than removes the underlying workload (Jumeau et al., 2021).

3.2 System Integration

Vendors and health systems describe “integration” primarily as interface-level connectivity — ADC-to-pharmacy-system interfaces, wholesaler electronic data interchange, and ERP procurement feeds. This form of integration synchronizes order and replenishment data but does not necessarily create a shared, transaction-level ledger of physical movement. Reviews of automated and semi-automated drug distribution systems find that safety and time benefits are strongest where automation is centralized and where verification is closed-loop (barcode- or RFID-confirmed at each handoff), and weaker where decentralized cabinets and manual override paths remain outside the automated record (Ahtiainen et al., 2020).

3.3 Artificial Intelligence in Pharmacy Supply Chains

AI applications reported in hospital pharmacy supply chains cluster around three uses: demand forecasting for procurement and shortage mitigation, anomaly and diversion detection on transaction logs, and image- or sensor-based verification (visual pill counting, computer-vision picking checks). Case reporting on health-system RFID and analytics deployments describes reductions in waste, stockouts, and technician search time, and substantial recovery of previously untracked high-cost inventory once real-time location data became available. These reports also make clear that the analytic layer's value is contingent on the completeness of the underlying data feed: AI forecasting and anomaly detection are described as most effective once real-time RFID or comparable tracking already resolves the physical-visibility problem, rather than as a substitute for it.

4. Problem Statement: The Persistence of Discrepancy

Three observations frame the problem this paper addresses:

- Accuracy improves but is not absolute. Even RFID-based cabinet inventory, among the most mature tracking modalities reported, is described in health-system case reporting as reaching very high but not perfect accuracy (on the order of 99.9%), meaning a residual and recurring variance remains even in leading deployments.
- Automation downtime reintroduces manual risk. Every automated system has a manual fallback procedure for outages, maintenance, or exception handling; each fallback event is a window in which physical movement can occur without a corresponding, verified digital transaction.
- Integration does not equal reconciliation. Interfaces that pass order and replenishment messages between systems do not, by themselves, verify that a specific physical unit

moved as recorded; verification requires a capture event (scan, tag read, weight check) at the point of handling, and any handling step without a capture event is a discrepancy waiting to surface.

The result is a recurring pattern across facilities regardless of how advanced their technology stack is: the system of record and the physical shelf drift apart between reconciliation events, and the size of that drift — not its existence — is what technology adoption changes.

5. Root-Cause Analysis

Table 1 summarizes how each root cause maps across the technology, data, and organizational layers before the detailed discussion below.

Root cause	Primary layer	Typical trigger	Section
Physical–digital reconciliation gap	Technology	Line-of-sight/tag-read failure	5.1
Human-in-the-loop failure points	Organizational	Manual entry at waste/borrow/return	5.2
Data latency & fragmentation	Data	Interface message delay across systems	5.3
AI forecasting/anomaly-detection limits	Data	Model trained on noisy transactional data	5.4
Governance & process gaps	Organizational	Undefined exception ownership	5.5

5.1 Physical–Digital Reconciliation Gaps

Barcode-based verification depends on line-of-sight scanning: a code that is rotated away from the sensor, obscured by packaging, or damaged in transit is invisible to the system even though the item is physically present. Industry analysis of hospital tray and cabinet replenishment describes this as the "invisible stockout" — a state in which the system reports availability that does not correspond to a locatable, unexpired, uncompromised unit, or conversely fails to detect a unit that is genuinely present but unreadable (Bluesight, n.d.-a). RFID reduces but does not eliminate this problem: tag placement on narrow-radius containers such as vials and syringes, tag damage from mechanical stress, and reader coverage gaps in refrigerators or non-instrumented storage locations all reproduce a smaller version of the same failure mode (Bluesight, n.d.-b; Manufacturing Chemist, n.d.).

5.2 Human-in-the-Loop Failure Points

Robotic and automated systems govern storage and picking, but many transaction-relevant events still occur outside the automation boundary: bedside administration, waste of partial doses, returns to stock, borrowing between units, multi-drug compounding, and patient-specific overrides during emergencies. Each of these is a point where a human must generate a transaction record manually, and any omitted, mistimed, or misattributed entry becomes a discrepancy that automation cannot self-correct because the physical event never entered its data stream.

5.3 Data Latency and System Fragmentation

Hospitals typically operate several systems of record — the ADC platform, the pharmacy information system, the EHR's medication administration record, the ERP/procurement platform, and, where deployed, a separate RFID or analytics layer. "Tight integration" in practice usually means scheduled or event-triggered interface messages between these systems rather than a single shared ledger. Timing differences between when a transaction occurs, when it is recorded locally, and when it propagates across interfaces create windows in which two systems legitimately disagree about quantity on hand, and reconciliation jobs must resolve these windows rather than assume instantaneous consistency.

5.4 Limits of AI Forecasting and Anomaly Detection

AI models used for demand forecasting, shortage prediction, or diversion detection are trained on the transactional data produced by the systems described above. Where that underlying data contains unresolved physical–digital gaps, an AI layer can propagate or even obscure the defect: a forecasting model will learn from historically inaccurate consumption data, and an anomaly-detection model tuned to typical discrepancy patterns can normalize a chronic data-quality problem rather than flag it as one requiring correction. AI adoption therefore narrows the consequence of discrepancy (better prediction despite noise, faster flagging of outliers) without necessarily narrowing the discrepancy itself unless it is paired with, rather than substituted for, improved point-of-capture verification.

5.5 Governance and Process Gaps

Case evaluations of automation implementations describe recurring organizational contributors: inconsistent manual-downtime procedures, override cultures that prioritize speed of patient care over transaction completeness (appropriately, in emergencies, but without a compensating fast-follow reconciliation step), unclear ownership of exception queues, and reconciliation cycles that are periodic (daily, weekly, or tied to counts) rather than continuous. These are process and accountability failures rather than technology failures, and they persist through technology upgrades unless explicitly redesigned alongside them. The scale of the resulting reporting gap has been quantified directly: a Markov-model analysis of roughly two million ADC transactions at a single health system found that just under one percent produced a quantity discrepancy, but only about six percent of those discrepancies generated a user report, and fewer than one in a thousand of the original transactions ever reached a formal patient-safety-event record (Fong et al., 2022). That funnel — from transaction, to discrepancy, to user report, to formal record — is itself a governance artifact: each step depends on a person choosing to escalate, and the analysis found no evidence that unreported discrepancies were systematically less clinically significant than reported ones, only that they were less visible.

6. Case Illustrations

Table 2 summarizes the three cases discussed below, each reported by a different automation or tracking deployment, alongside the residual gap each case reports even after implementation.

Case	Setting	Technology	Reported outcome	Residual gap
6.1 Combined ADC + robot	Australia, acute-care hospital	ADC + inventory robot	Picking accuracy improved; total distribution time not consistently reduced	Restocking time rose; downtime reverted staff to manual, error-prone workflow
6.2 RFID cabinet + satellite pharmacy	United States, pediatric hospital	RFID-tagged cabinet inventory	Cabinet accuracy raised to ~99.99%; high-cost inventory (e.g., clotting factor) recovered	Accuracy explicitly short of full reconciliation (Section 4)
6.3 RFID for OR anesthesia workstation	United States, 800-bed regional medical center	RFID at OR/anesthesia handoff	Technician time recovered; stockouts reduced	Discrepancy concentrated at the systems handoff itself, not within either system

6.1 Combined ADC and Inventory-Robot Deployment (Australia)

A prospective observational evaluation at an Australian acute-care hospital compared medication supply workflows before and after implementing ADCs and inventory robots for central distribution. Absent automation downtime, overall distribution time fell significantly; however, an automation outage during the post-implementation period forced a return to manual procedures, and restocking time for the ADCs increased significantly post-implementation — illustrating that automation shifts labor and risk rather than eliminating the manual, error-prone steps entirely (Fox et al., 2021).

6.2 RFID-Based Cabinet and Satellite Pharmacy Tracking (United States)

A pediatric hospital's satellite pharmacy identified that roughly eight to ten percent of its drug budget — tens of millions of dollars of inventory — was untracked under its prior semi-automated, barcode-and-manual-count workflow. Deploying RFID tagging with automated reads reduced per-item tagging time from roughly two minutes to seven seconds and raised cabinet inventory accuracy to approximately 99.99 percent, while restoring visibility into previously "lost" high-cost inventory such as clotting factor products (Zebra Technologies, n.d.). The reported accuracy, while very high, is explicitly short of full reconciliation, consistent with the residual-gap pattern described in Section 4.

6.3 RFID for Operating-Room Anesthesia Workstation Inventory

An 800-bed regional medical center reported that inventory visibility diminished specifically at the point where medications left central pharmacy tracking and entered anesthesia workstations in the operating room — a classic handoff gap. Implementing RFID at that handoff recovered technician time and reduced stockouts, but the case is notable for locating the discrepancy precisely at a transition between systems rather than within either automated system alone, reinforcing that integration boundaries, not any single technology, are where discrepancy concentrates (Becker's Hospital Review, 2024).

7. Discussion: Toward a Reconciliation Framework

The evidence supports reframing the question from "why hasn't automation eliminated discrepancy" to "where, specifically, does the digital record stop observing the physical item, and what closes that observation gap." Four principles follow:

- Verification, not just automation, at every handoff. Each physical transition — wholesaler to central pharmacy, central pharmacy to ADC, ADC to point of care, point of care to patient or waste — needs a capture event, not merely an interface message inferring that the transition occurred.
- Continuous rather than periodic reconciliation. Where feasible, exception detection should run against live transaction streams rather than waiting for scheduled counts, shortening the window in which drift accumulates undetected.
- Data quality as a precondition for AI value. Forecasting and anomaly-detection models should be paired with explicit data-quality monitoring on their input streams; an AI system deployed on top of an unresolved reconciliation gap will optimize around the gap rather than close it.
- Named ownership of exception handling. Downtime procedures, override events, and manual entries need a designated accountable role and a fast-follow reconciliation step, so that speed-of-care exceptions do not silently become permanent inventory variances.

None of this argues against continued investment in robotics, integration, or AI — the case evidence above shows real, measurable gains in accuracy, safety, and recovered inventory value. The argument is that the residual discrepancy is a structural feature of multi-system, multi-handler medication supply chains, and will not be fully eliminated by adding more automation of the same kind; it requires closing observation gaps at handoffs and treating reconciliation as a continuous, governed process rather than an audit event.

8. RECOMMENDATIONS

- Map every physical handoff in the medication supply chain and confirm a capture event exists at each one; treat any handoff without one as a known, prioritized discrepancy source.
- Extend tracking (barcode, RFID, or sensor-based) beyond central pharmacy and ADCs into the last-mile settings where visibility is reported to diminish most — operating rooms, anesthesia workstations, and satellite/float stock.
- Establish a standard, time-bound manual-downtime procedure that includes a mandatory reconciliation pass once systems are restored.
- Monitor AI forecasting and anomaly-detection models for input data quality, not only output accuracy, and route flagged anomalies to a named reconciliation owner with a service-level target for resolution.
- Report discrepancy rate and time-to-reconciliation as standing operational metrics, alongside dispensing accuracy and stockout rate, so that residual gaps remain visible rather than being absorbed into routine variance.

9. LIMITATIONS

This review has four limitations that should guide how its conclusions are used. First, it is a narrative rather than a systematic review: source identification and screening were performed by a single reviewer without dual-reviewer verification or a PRISMA flow diagram, so selection bias cannot be excluded. Second, the peer-reviewed evidence base is drawn from a small number of systematic reviews and single-site evaluations concentrated in Europe, Australia, and North America; findings may not generalize to low-resource settings or to hospital systems with materially different staffing models. Third, several of the illustrative cases in Section 6 are drawn from vendor- or health-system-published case reports rather than peer-reviewed, independently audited outcomes, and are presented explicitly as illustrative rather than as generalizable effect sizes. Fourth, because AI applications in this domain are evolving rapidly, the specific tools referenced may not reflect the current state of commercially deployed systems at the time of publication; the structural argument (that AI is data-dependent rather than data-correcting) is intended to remain valid independent of any specific product generation.

CONCLUSION

Robotics, system integration, and AI have measurably improved dispensing accuracy, recovered previously untracked inventory, and reduced stockouts in hospital pharmacies, as the reviewed evaluations and case reports demonstrate. They have not eliminated stock discrepancies in hold and transaction records, because discrepancy originates at physical–digital observation gaps — principally at human-handled handoffs and system boundaries — that automation narrows without fully closing and that AI can only analyze, not repair, on its own. Sustained progress requires pairing continued technology investment with deliberate verification at every handoff, continuous reconciliation processes, and clear accountability for exceptions, rather than expecting adoption of any single technology to resolve a structurally distributed problem.

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