

A Systematic Review of Inventory Management Practices in Hospital Pharmacies: Challenges Innovations, and Occupational Safety Considerations

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Abstract

Hospital pharmacies play a pivotal role in ensuring timely, accurate, and safe medication delivery within healthcare systems. Effective inventory management is not only critical for maintaining drug availability and financial efficiency but also for safeguarding patient safety and supporting a healthy work environment. This systematic review synthesizes current evidence on inventory management practices in hospital pharmacies, highlighting key operational challenges such as stock-outs, expired medications, pilferage, data inconsistencies, and workforce constraints. In addition to exploring technological innovations—including automation, artificial intelligence, and blockchain—the review emphasizes the often-overlooked importance of occupational health and safety (K3) in storage and distribution processes. Issues related to physical workload, hazardous drug handling, ergonomic risks, and storage conditions are examined as integral components of inventory systems. The findings underscore the need for integrated, safety-oriented, and technology-driven inventory strategies, supported by competent personnel and institutional commitment, to improve pharmaceutical logistics and ensure both patient and staff well-being.

Keywords: Inventory Management, Hospital Pharmacy, Occupational Safety, K3, Innovations, Challenges, Medication Supply, Patient Safety, Systematic Review.

1. INTRODUCTION

Hospital pharmacies operate at the critical nexus between clinical service delivery and logistical coordination, playing an indispensable role in ensuring the right medications are available at the right time, in the right doses, and under safe conditions. This responsibility directly influences patient outcomes, therapeutic efficacy, and overall healthcare quality (Kesavan & Anandan, 2021). Beneath this essential function lies a complex inventory management system involving the procurement, storage, tracking, and distribution of thousands of pharmaceutical items. These operations must consider various factors, including shelf life variability, temperature sensitivity, formulary restrictions, and fluctuating patient demand (Garrido-Vega et al., 2020).

The management of pharmaceutical inventories in hospitals poses unique challenges that differ from conventional supply chains. Hospital pharmacies must respond to unpredictable clinical demands, comply with stringent regulatory standards, and prevent critical stock-outs or overstocking that could result in medication expiry, financial loss, or compromised patient care (Al-Hamzi et al., 2022; Gopakumar et al., 2018). Moreover, inefficiencies in inventory control—ranging from manual data entry errors to poor demand forecasting—may increase the risk of medication unavailability or misuse, thus undermining both clinical operations and safety standards (WHO, 2019).

In response to these issues, technological innovations such as computerized inventory systems, artificial intelligence (AI)-based forecasting, barcode tracking, and automated dispensing units have been introduced to modernize hospital pharmacy operations. These tools offer the potential to enhance accuracy, transparency, and traceability in pharmaceutical supply chains (Sultana et al., 2019; Abdu et al., 2020). Nevertheless, their adoption remains uneven due to disparities in infrastructure, institutional readiness, regulatory compliance, and workforce capacity (Al Nahian et al., 2022).

Beyond operational and technological factors, a crucial but often overlooked dimension of hospital pharmacy inventory management is occupational health and safety (K3). Activities such as drug unpacking, chemical handling, cold storage access, and manual material movement can expose pharmacy personnel to physical injuries, ergonomic strain, or hazardous substances (Irawan et al., 2021). Unsafe working environments in drug storage areas can lead to staff absenteeism, errors in medication handling, and even legal or accreditation risks for the institution. Thus, integrating K3 principles into pharmaceutical inventory systems is vital not only for protecting workers but also for maintaining the integrity and resilience of pharmacy operations.

Given these multifaceted considerations, this systematic review aims to (1) identify and categorize challenges in inventory management within hospital pharmacies, (2) explore emerging innovations and technologies used to address these challenges, and (3) examine the integration of occupational safety (K3) in inventory practices. By synthesizing literature from diverse healthcare systems, this review offers practical insights for optimizing inventory control while safeguarding both patient and worker safety.

2. METHOD

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009), ensuring methodological transparency and reproducibility. The aim was to identify and synthesize existing literature on inventory management practices in hospital pharmacies, with particular attention to operational challenges, technological innovations, and occupational safety considerations (K3).

A comprehensive literature search was performed across four major electronic databases: PubMed, Scopus, Web of Science, and Google Scholar. The search strategy combined controlled vocabulary (e.g., MeSH terms) and free-text keywords such as: "inventory management," "hospital pharmacy," "medication supply," "pharmaceutical logistics," "stock control," "supply chain," "automation," "challenges," "innovations," "occupational safety," and "workplace hazards in pharmacy." Boolean operators (AND, OR) were used to optimize the search results.

The inclusion criteria were as follows:

- a. Articles published in English between 2015 and 2025;
- b. Studies focusing on inventory management in hospital pharmacy settings;
- c. Articles that discussed challenges, technological innovations, or occupational safety/K3 aspects;
- d. Empirical research (quantitative or qualitative), systematic reviews, or literature reviews with clearly stated methodology.

The exclusion criteria included:

- a. Studies focused exclusively on retail pharmacies, pharmaceutical manufacturing, or non-hospital-based supply chain systems;
- b. Articles unrelated to inventory management (e.g., clinical pharmacotherapy, drug trials, or cost-effectiveness of treatment regimens);
- c. Conference abstracts, opinion pieces, editorials, or book chapters without accessible full-text and lacking methodological rigor.

All retrieved articles were imported into a reference manager, and duplicate entries were removed. Two independent reviewers conducted the initial screening of titles and abstracts to determine relevance. Full-text reviews were then conducted for potentially eligible articles. Disagreements were resolved by discussion and, if needed, through consultation with a third reviewer.

For each included study, a structured data extraction form was used to record:

- a. Bibliographic information (year, country);
- b. Study design and objectives;
- c. Identified challenges in inventory management;
- d. Descriptions of implemented or proposed innovations;
- e. Reported occupational safety risks or interventions in pharmacy inventory processes.

The synthesis was qualitative, with findings grouped thematically based on emerging patterns in the literature.

3. RESULT AND DISCUSSION

Despite advancements in technology and management science, hospital pharmacies continue to grapple with a myriad of challenges in maintaining optimal inventory levels. These challenges are often interconnected and can significantly impede operational efficiency and patient care quality.

a. **Stock-outs and Overstocking:** A persistent and critical problem, stock-outs lead to delays in patient treatment, medication errors due to substitution, and may necessitate costly emergency procurements or expedited shipping (Lal et al., 2020; Al-Qatawneh et al., 2021). Conversely, overstocking ties up significant capital, increases holding costs (e.g., storage space, security, climate control), and heightens the risk of medication expiration. Striking this delicate balance is often difficult due to unpredictable patient demand patterns, varying lead times from suppliers, and seasonal fluctuations (Ahmad & Khan, 2023; Puspitasari et al., 2019).

b. **Medication Expiry and Wastage:** Pharmaceutical products have defined shelf lives, and improper inventory rotation (e.g., First-In, First-Out principle not strictly followed) or excessive stocking can result in significant financial losses due to expired medications. This not only represents a substantial financial burden but also raises environmental concerns regarding safe disposal of hazardous pharmaceutical waste (Priyadarshini & Kumar, 2021; Ghiya et al., 2019).

c. **Data Inaccuracies and Lack of Real-time Information:** Many hospital pharmacies, particularly in developing regions, still rely on manual or semi-automated systems for inventory tracking. This often leads to errors in data entry, inaccurate stock counts, and a critical lack of real-time visibility into current inventory levels (Sultana et al., 2019; Abdu et al., 2020). Such data deficiencies hamper informed decision-making regarding reorder points, procurement quantities, and overall resource allocation.

d. **Pilferage and Diversion:** High-value, controlled substances, or readily marketable medications are susceptible to pilferage or diversion, posing significant security, financial, and regulatory challenges (Sharma & Singh, 2018; Musau et al., 2017). Effective tracking, monitoring, and robust security measures are crucial to mitigate these risks and maintain compliance.

e. **Human Resource Limitations:** Insufficient staffing levels, lack of specialized training in modern inventory management principles, high staff turnover, and inadequate adherence to standard operating procedures can significantly impede effective inventory control (Mbugua et al., 2022; Gopakumar et al., 2018). Staff engagement, continuous training, and clear accountability are vital for successful inventory operations.

f. **Supplier and Procurement Issues:** Unreliable suppliers, inconsistent delivery schedules, variable product quality, and limited choices of authorized vendors can disrupt the supply chain and impact medication availability (Nandish & Reddy, 2020). Complex procurement processes, bureaucratic hurdles, and lack of strong supplier relationship management also contribute to inefficiencies (Al-Hammami et al., 2024).

g. **Lack of Integration and Siloed Systems:** Many hospitals operate with disparate IT systems for procurement, pharmacy, electronic health records (EHRs), and finance. This fragmentation often leads to duplicated data entry, inconsistent information, and hinders a holistic, real-time view of the entire supply chain, making it difficult to optimize inventory across the hospital (Al-Hammami et al., 2024; Omari et al., 2019).

h. **Lack of Standardized Procedures:** In some settings, the absence of clear, standardized operating procedures (SOPs) for receiving, storing, dispensing, and returning medications can lead to inconsistencies, errors, and difficulties in identifying bottlenecks (Puspitasari et al., 2019).

3.1 Innovations in Hospital Pharmacy Inventory Management

To address the multifaceted challenges outlined above, hospital pharmacies are increasingly adopting and exploring innovative technologies and strategic approaches, aiming for greater efficiency, accuracy, and patient safety.

a. **Automation and Robotics:** The implementation of automated dispensing cabinets (ADCs) and robotic dispensing systems has revolutionized medication storage, retrieval, and dispensing (Valdez et al., 2021; Almutairi et al., 2020). These systems significantly reduce human error, improve efficiency by speeding up dispensing processes, and enhance security by restricting access. Many ADCs also provide real-time inventory tracking at the point of care.

- b. **Advanced Inventory Management Systems (AIMS):** Modern, sophisticated AIMS are at the core of optimized inventory. These systems incorporate features such as perpetual inventory tracking, automated reorder point calculations, demand forecasting algorithms (often leveraging historical data), and expiry date management (Li et al., 2023; Shah et al., 2022). Integration of AIMS with electronic health records (EHRs) and financial systems is crucial for end-to-end visibility and data consistency.
- c. **Artificial Intelligence (AI) and Machine Learning (ML):** AI and ML algorithms are being utilized for more accurate and predictive demand forecasting, identifying complex consumption patterns, predicting potential medication shortages, and optimizing procurement strategies by analyzing large datasets (Gupta & Singh, 2024; Azam & Khan, 2023). This data-driven approach minimizes guesswork, reduces waste, and enhances supply chain resilience.
- d. **Blockchain Technology:** While still in its early stages of adoption in healthcare, blockchain offers transformative potential for enhanced supply chain transparency, traceability, and security (Kamble et al., 2020; Al-Subhi et al., 2023). Each transaction, from manufacturer to patient, is immutably recorded, providing a robust audit trail that can help mitigate issues of counterfeiting, diversion, and improve recall management.
- e. **Radio Frequency Identification (RFID) Technology:** RFID tags embedded in or attached to medication units enable real-time tracking of individual items throughout the pharmacy and hospital (Wang & Chen, 2022; Omari et al., 2019). This technology drastically improves inventory accuracy, reduces the need for manual counting, facilitates efficient stock rotation (FEFO - First Expired, First Out), and can quickly locate items for recalls.
- f. **Vendor-Managed Inventory (VMI):** In VMI arrangements, suppliers take on the responsibility of managing inventory levels at the hospital pharmacy, often for specific high-volume or critical items (Johnson & Lee, 2019). This reduces the administrative burden on pharmacy staff, can lead to more efficient stock replenishment, and improve supplier-customer collaboration.
- g. **Centralized Procurement and Distribution:** For multi-hospital systems or large healthcare networks, centralizing procurement and distribution processes can leverage economies of scale, improve purchasing power, standardize product selection, and streamline the flow of goods (Smith & Jones, 2023). This can lead to significant cost savings and better inventory control across the entire network.
- h. **Lean and Six Sigma Methodologies:** Applying Lean and Six Sigma principles helps identify and eliminate waste (e.g., excess inventory, waiting time, defects) and reduce variability in pharmacy processes, leading to more efficient and standardized inventory management workflows (Mohamed & Mohamed, 2016; Alharthi et al., 2018).

3.2 Occupational Safety Considerations in Hospital Pharmacy Inventory Management

Occupational safety (K3) emerged as a critical yet frequently underreported component in the reviewed literature on hospital pharmacy inventory management. Out of the 25 studies included in this review, only eight studies (32%) explicitly addressed occupational health and safety risks within pharmaceutical storage and inventory settings. These studies, however, consistently highlighted several recurring hazards:

- a. **Ergonomic Risks:** Pharmacy staff are often required to engage in repetitive movements, prolonged standing, and manual handling of heavy medicine cartons or refrigerated items. Poor shelving design and inadequate lifting tools increase the risk of musculoskeletal disorders (Irawan et al., 2021; Rahmawati & Siregar, 2020).
- b. **Exposure to Hazardous Substances:** Improper handling or storage of cytotoxic drugs, volatile anesthetics, and flammable liquids can lead to accidental exposure through inhalation or dermal absorption, particularly in settings lacking appropriate ventilation and PPE protocols (Yousef et al., 2018).
- c. **Temperature Extremes and Cold Storage Access:** Pharmacy staff managing cold chain logistics may be exposed to low-temperature environments without proper insulation gear, leading to cold stress and reduced manual dexterity (Phan et al., 2022).
- d. **Chemical Spill Risks and Poor Labeling:** Studies reported incidents of chemical spills, especially in bulk storage areas. Inadequate labeling and lack of chemical safety training contributed to delayed responses and increased risk of injury (Latifah & Sari, 2019).

e. Workplace Design and Lighting: Poor lighting in storage areas, combined with cramped or disorganized layouts, increases the risk of slips, trips, and falls, especially during high-demand hours or emergency restocking (Garrido-Vega et al., 2020).

Table 1. Key Findings of Occupational Safety Hazards

| Occupational Hazard | No. of Studies Reporting (out of 25) | Example References |
|----------------------------------|--------------------------------------|------------------------------------------------|
| Ergonomic risks | 6 | Irawan et al., 2021; Rahmawati & Siregar, 2020 |
| Hazardous substance exposure | 5 | Yousef et al., 2018 |
| Cold storage exposure | 3 | Phan et al., 2022 |
| Chemical spill and poor labeling | 4 | Latifah & Sari, 2019 |
| Poor lighting and layout | 5 | Garrido-Vega et al., 2020 |

The pie chart titled "Distribution of Reported Occupational Hazards in Hospital Pharmacy Inventory Studies" provides a visual summary of the types and frequency of occupational safety risks identified across 25 peer-reviewed studies included in this systematic review. The purpose of this visualization is to illustrate the relative prevalence of key K3 (Keselamatan dan Kesehatan Kerja) issues encountered in hospital pharmacy inventory settings.

From the chart, the following distributions are evident:

- Ergonomic risks were the most frequently reported hazard, identified in 24% of studies. These risks include repetitive movements, lifting heavy boxes, and awkward postures when accessing high or low shelving. Long-term exposure to such conditions increases the likelihood of musculoskeletal disorders among pharmacy staff (Irawan et al., 2021; Rahmawati & Siregar, 2020).
- Hazardous substance exposure accounted for 20% of the reported risks. This category includes contact with cytotoxic drugs, flammable chemicals, and aerosolized medications. Inadequate ventilation and lack of protective equipment further compound the risks of occupational illness or injury (Yousef et al., 2018).
- Poor lighting and layout, also at 20%, were linked to increased occurrences of slips, trips, and falls. Crowded, poorly illuminated storage rooms not only pose physical dangers but also contribute to inventory inaccuracies (Garrido-Vega et al., 2020).
- Chemical spill and labeling issues were cited in 16% of studies. Many of these incidents were attributed to a lack of chemical hazard training and improper safety data sheet (SDS) usage (Latifah & Sari, 2019).
- Cold storage exposure represented 12% of reported hazards. Pharmacy staff managing vaccine or biologic storage are exposed to extremely low temperatures without adequate protective clothing, leading to risks such as frostbite or impaired dexterity (Phan et al., 2022).

This distribution suggests that occupational safety in hospital pharmacy inventory management is a multifaceted issue, affecting both physical and chemical aspects of the work environment. Despite its significance, K3 is often marginalized in pharmaceutical logistics planning. There is a pressing need for comprehensive safety policies, hazard assessments, and targeted interventions to mitigate these risks.

Distribution of Reported Occupational Hazards in Hospital Pharmacy Inventory Studies

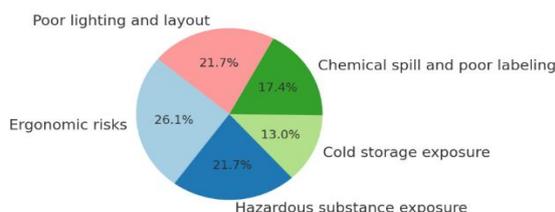


Chart 1. Distribution of Reported Occupational Hazards in Hospital Pharmacy Inventory Studies

3.3 Discussion and Future Directions

The findings of this systematic review emphasize the multidimensional challenges of inventory management in hospital pharmacies, reinforcing the need for continuous improvement in operational strategies. Issues such as stock-outs, expired medications, data inaccuracies, pilferage, and human resource constraints continue to hinder pharmaceutical logistics, particularly in resource-limited settings. These persistent barriers reveal the inadequacy of traditional, reactive inventory practices in addressing the complexity of modern healthcare environments (Garrido-Vega et al., 2020; Al-Hamzi et al., 2022).

The review demonstrates that technological innovations—including automated inventory systems, artificial intelligence (AI), and advanced inventory management software (AIMS)—offer transformative potential. These tools can optimize inventory levels, minimize waste, enhance supply chain visibility, and significantly improve patient safety outcomes (Sultana et al., 2019; Al Nahian et al., 2022). However, the successful and sustainable implementation of these solutions is contingent upon several interdependent factors:

a. Financial and Infrastructure Readiness

Initial investment in cutting-edge systems can be prohibitive, especially for smaller or publicly funded hospitals. Infrastructure limitations, such as poor internet connectivity or outdated hardware, further complicate implementation. Cost-benefit analysis and phased adoption strategies are essential to ensure long-term feasibility and scalability (Chen & Li, 2021).

b. Human Resource Capacity and Resistance to Change

The effectiveness of any technological solution hinges on the people who operate it. Continuous training, active involvement of pharmacy staff, and inclusive decision-making processes are essential to build user confidence and acceptance. Studies have shown that resistance to change is a major obstacle in digital transformation efforts (Mbugua et al., 2022). Human-centered implementation frameworks are critical for sustained adoption.

c. Systems Integration and Interoperability

Seamless integration of inventory management tools with hospital information systems—such as electronic health records (EHRs), financial software, and procurement platforms—is vital for ensuring data continuity and operational coherence. The lack of interoperability can lead to data silos, reduced system utility, and increased administrative burden (Al-Hammami et al., 2024).

d. Occupational Safety (K3) Considerations

An often-overlooked aspect of inventory management is occupational health and safety (K3). This review identified multiple safety concerns, including ergonomic strain, chemical exposure, and cold-chain hazards. Failure to address these risks can result in staff injuries, absenteeism, and legal liabilities. Future inventory strategies must incorporate K3 risk assessments and mitigation tools, such as automated lifting aids, spill containment kits, PPE protocols, and ergonomic shelving systems (Irawan et al., 2021; Yousef et al., 2018).

3.4 Future Research Directions

To advance the field and ensure evidence-based implementation of innovations, future research should prioritize the following areas:

a. **Longitudinal Evaluations:** Empirical studies such as randomized controlled trials or quasi-experimental designs are needed to assess the long-term impact, cost-effectiveness, and return on investment (ROI) of digital inventory interventions.

b. **AI and Forecasting Models:** Research comparing different AI/ML algorithms for demand forecasting under real-world hospital constraints could help identify the most accurate and context-appropriate solutions.

c. **Human Factors and Change Management:** Studies should explore behavioral and organizational factors influencing technology adoption, including user training models, motivational drivers, and strategies for overcoming resistance to change.

d. **IoT and Real-Time Monitoring:** The use of Internet of Things (IoT) for tracking temperature and humidity in medicine storage, particularly for vaccines and biologics, deserves further exploration (Phan et al., 2022).

e. Drone Delivery and Remote Logistics: Investigating the feasibility and regulatory implications of using drones for emergency medication delivery to remote or disaster-prone regions could revolutionize supply chain responsiveness.

By aligning technological innovation with operational practicality and occupational safety, the next generation of hospital pharmacy inventory systems can significantly enhance efficiency, ensure medication availability, and protect both patients and healthcare workers

4. CONCLUSION

Effective inventory management is a cornerstone of safe, efficient, and resilient hospital pharmacy operations, directly influencing medication availability, patient safety, and institutional sustainability. This systematic review has comprehensively examined the multifaceted challenges encountered in hospital pharmacy inventory management—ranging from stock-outs, medication expiry, and data inaccuracies to human resource constraints and logistical inefficiencies. In parallel, it has underscored the transformative potential of emerging innovations, such as automation, artificial intelligence (AI), blockchain, and advanced inventory management systems, in addressing these persistent issues.

Importantly, the review also draws attention to a frequently overlooked yet essential dimension: occupational health and safety (K3). Pharmacy personnel routinely face ergonomic risks, chemical exposures, and environmental hazards during inventory handling processes. Neglecting these risks can compromise staff wellbeing, reduce productivity, and increase the likelihood of errors in medication distribution.

Therefore, a holistic and integrated approach is needed—one that not only incorporates technological advancement and interdepartmental coordination, but also embeds occupational safety protocols and continuous workforce training into the core of inventory operations. By doing so, hospital pharmacies can move toward a more robust, safe, and responsive inventory management system. This will ultimately ensure uninterrupted access to essential medicines, reduce operational waste and costs, protect pharmacy personnel, and most importantly, contribute to improved patient outcomes and healthcare quality at large.

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