International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(REVIEW ARTICLE)

Check for updates

Economic evaluation of digital pharmacy platforms in reducing medication errors and operational healthcare costs

Inarumen Ohis Genesis *

Department of Management and Accounting, Obafemi Awolowo University, Ile Ife, Nigeria.

International Journal of Science and Research Archive, 2021, 04(01), 311-328

Publication history: Received on 13 October 2021; revised on 23 November 2021; accepted on 25 November 2021

Article DOI: https://doi.org/10.30574/ijsra.2021.4.1.0177

Abstract

The digital transformation of pharmacy services presents significant opportunities to enhance medication safety, reduce healthcare costs, and improve operational efficiency. Digital pharmacy platforms, encompassing e-prescribing systems, automated dispensing units, telepharmacy services, and clinical decision support tools, are being increasingly adopted across healthcare systems to address longstanding challenges such as medication errors, inefficiencies in drug distribution, and fragmented patient data. This study provides a comprehensive economic evaluation of digital pharmacy platforms, focusing on their effectiveness in reducing medication-related errors and optimizing resource utilization. From a macroeconomic perspective, medication errors account for a substantial portion of preventable harm and healthcare expenditure globally. These errors, often resulting from manual transcription, miscommunication, and lack of clinical context, lead to extended hospital stays, readmissions, and adverse patient outcomes. Digital platforms mitigate these risks through automation, real-time data validation, and integration with electronic health records (EHRs), thus improving prescribing accuracy and workflow continuity. The paper applies cost-effectiveness analysis (CEA), cost-benefit analysis (CBA), and budget impact modeling to assess the return on investment (ROI) of digital pharmacy implementations in both hospital and outpatient settings. It also explores indirect economic benefits, including reduced administrative burden, improved inventory management, and enhanced pharmacist productivity. Furthermore, case studies from multi-center health systems and rural telepharmacy programs are presented to illustrate how digital solutions contribute to healthcare equity and access. By quantifying financial and clinical outcomes, this evaluation underscores the critical role of digital pharmacy platforms in advancing safe, efficient, and economically sustainable healthcare delivery.

Keywords: Digital Pharmacy; Medication Safety; Cost-Effectiveness; Health Economics; Tele-pharmacy; Operational Efficiency

1. Introduction

1.1. Background: Digital Disruption in Healthcare

Digital transformation is fundamentally reshaping the healthcare industry across the globe. Emerging technologies such as artificial intelligence (AI), machine learning (ML), Internet of Things (IoT), and big data analytics are being increasingly deployed to enhance operational efficiency, optimize clinical outcomes, and reduce costs [1]. This wave of transformation—often referred to as the Fourth Industrial Revolution in healthcare—has spurred innovation in diagnostics, remote monitoring, robotic surgeries, and virtual care platforms [2].

Pharmacy practice is not exempt from this disruption. In recent years, the sector has witnessed rapid digitalization through pharmacy automation, electronic prescribing, and the rise of e-health solutions that enable digital medication

* Corresponding author: Inarumen Ohis Genesis.

reconciliation, inventory management, and patient engagement [3]. Robotic dispensing units, barcode verification systems, and AI-powered clinical decision support tools are now integrated into hospital and community pharmacy workflows in many developed and developing countries [4].

Furthermore, the adoption of digital health records and telepharmacy services has extended the reach of pharmaceutical care to remote and underserved areas, while simultaneously improving the traceability and safety of medication use [5]. These innovations offer significant promise in mitigating longstanding inefficiencies, reducing manual errors, and aligning pharmaceutical services with the principles of value-based healthcare.

However, with the acceleration of digital integration comes the need for robust evaluation frameworks. It is no longer sufficient to assess technology adoption based on technical feasibility alone—**economic evaluation** has become essential for measuring long-term impact, sustainability, and health system alignment [6].

1.2. The Burden of Medication Errors

Medication errors are among the most common and preventable causes of harm in healthcare systems worldwide. The World Health Organization (WHO) estimates that such errors contribute to at least **one death every day** and injure approximately 1.3 million people annually in the United States alone [7]. These incidents range from incorrect dosages and drug interactions to failures in prescribing, dispensing, or administering medications [8].

Globally, the economic toll of medication-related errors is staggering. WHO reports suggest that the total cost of medication errors may exceed $42 billion annually, not including indirect costs such as reduced productivity, caregiver burden, and litigation expenses [9]. Low- and middle-income countries bear a disproportionate share of this burden, often lacking robust systems for surveillance, accountability, and error mitigation [10].

The implications for patient safety are equally grave. Medication errors frequently result in avoidable hospitalizations, prolonged stays, and increased morbidity, particularly among the elderly and those with polypharmacy regimens [11]. These effects ripple across the continuum of care, leading to increased healthcare utilization and undermining public trust in health systems.

Within this context, digital health technologies—including automated verification systems, electronic prescribing platforms, and AI-enhanced clinical alerts—offer promising avenues for risk reduction [12]. Yet, without structured economic evaluations, decision-makers may struggle to distinguish between high-value innovations and costly technological overreach [13].

Pharmacists, as stewards of medication safety, must therefore advocate for evidence-based integration of digital tools that reduce error incidence while remaining aligned with fiscal and operational realities [14]. This necessitates not only technological proficiency but also a firm grounding in health economics and systems thinking.

1.3. Objectives and Relevance of Economic Evaluation

Given the twin pressures of rising healthcare costs and the demand for improved patient outcomes, cost-conscious innovation has become an imperative in global health policy. Stakeholders increasingly seek assurance that digital health interventions provide value—not just in technical performance, but in measurable gains across clinical and economic dimensions [15]. This is especially true in pharmacy, where the volume and complexity of medication use continue to rise alongside demographic changes and disease burdens.

The objective of this study is to explore the economic rationale for adopting pharmacy automation and e-health solutions aimed at reducing medication errors in hospital and health system settings. It seeks to assess the extent to which these technologies contribute to patient safety while also demonstrating cost-effectiveness and budgetary sustainability [16].

Specifically, this paper will examine the integration of economic evaluation frameworks—such as cost-effectiveness analysis (CEA), cost-utility analysis (CUA), and budget impact modeling—into the strategic planning and implementation of digital pharmacy innovations [17]. In doing so, it highlights the evolving role of pharmacists in shaping procurement, reimbursement, and technology adoption decisions.

The study contributes to the literature by synthesizing evidence from clinical practice, policy guidelines, and case studies across high- and middle-income settings. It also emphasizes the necessity of pharmacist-led economic evaluation as a key enabler of safe, sustainable, and patient-centered digital transformation [18].

Ultimately, this research reinforces the principle that innovation in healthcare must be evaluated not just for what it can do, but for what it is worth, especially in an era of limited resources and heightened expectations.

2. Components and architecture of digital pharmacy platforms

2.1. Overview of Digital Pharmacy Tools

Digital pharmacy tools have become central to transforming medication management in both inpatient and outpatient settings. Among the most widely adopted innovations are electronic prescribing (e-prescribing) platforms, automated dispensing cabinets (ADCs), and clinical decision support systems (CDSS), which collectively reduce human error, streamline workflows, and improve treatment accuracy [5].

E-prescribing systems enable prescribers to generate, transmit, and manage medication orders electronically, eliminating illegible handwriting, reducing transcription errors, and improving tracking of refill history [6]. Integration with national drug databases and formulary systems allows providers to make informed decisions at the point of care, including dose adjustment based on renal function or contraindications.

Automated dispensing technologies, such as robotics and ADCs, support secure storage, tracking, and dispensing of medications within hospital pharmacies and nursing units. These systems are programmed with patient-specific instructions and barcoding protocols, ensuring the right drug and dose reach the correct patient, while minimizing reliance on manual handling [7].

Meanwhile, clinical decision support systems offer real-time guidance to pharmacists and clinicians by flagging potential drug interactions, duplications, allergies, and therapeutic duplicity. These alerts are often embedded within electronic health records (EHRs), making them accessible at critical decision points [8]. Advanced CDSS platforms may also include pharmacogenomic data, helping to personalize therapy based on patient-specific genetic profiles.

Together, these tools form the digital backbone of modern pharmacy practice. Their combined functionality enhances medication safety, improves operational efficiency, and provides the analytical data needed to monitor outcomes and compliance with evidence-based guidelines [9]. However, their true value emerges when deployed as part of an integrated infrastructure aligned with clinical workflows and patient care pathways.

2.2. Technology Stack and Integration with EHRs

The successful implementation of digital pharmacy tools depends heavily on a robust technology stack capable of seamless communication with other health information systems, particularly electronic health records (EHRs). This integration is essential to ensure real-time access to patient data, synchronized medication orders, and interoperable analytics across care settings [10].

At the foundational level, the stack consists of several layers. The data layer stores structured and unstructured health information—including patient demographics, medication histories, allergies, and lab results—in relational databases or cloud-based repositories. Above this sits the application layer, which hosts pharmacy-specific platforms such as e-prescribing, dispensing systems, and CDSS tools [11].

The most critical component facilitating communication between these layers is the Application Programming Interface (API) layer. APIs act as conduits that enable different systems—such as EHRs, laboratory information systems (LIS), and billing platforms—to exchange data efficiently and securely. In pharmacy informatics, APIs support medication reconciliation, drug inventory updates, and real-time clinical alerts directly within the EHR interface [12].

Modern digital pharmacy platforms are increasingly designed to comply with interoperability standards such as HL7 FHIR (Fast Healthcare Interoperability Resources), which ensures consistency in how health data is formatted and exchanged across platforms [13]. This is particularly important in multi-center or cross-regional networks, where fragmentation of systems can lead to medication duplication, missed interactions, or discrepancies in documentation.

Additionally, middleware and service bus technologies act as translators that standardize data exchange among legacy and modern applications. These technologies enable integration of new digital tools without requiring a complete overhaul of existing infrastructure, thereby improving scalability and cost-effectiveness [14].

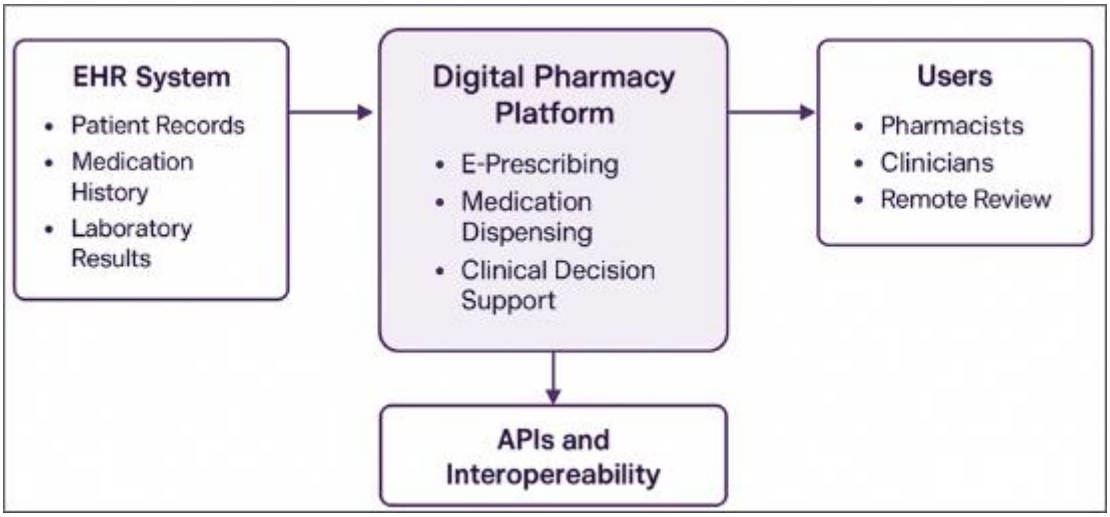

Figure 1 Architecture of a Digital Pharmacy Platform Integrated with EHRs

Ultimately, a well-orchestrated technology stack supports end-to-end digital medication management—from prescription to administration—while reinforcing clinical oversight and data-driven decision-making across the health system [15].

2.3. User Roles and Workflow Design

While technology enables transformation, its impact is contingent on well-designed workflows and clearly defined user roles within the clinical environment. In the context of digital pharmacy platforms, key users include pharmacists, prescribing clinicians, nurses, and remote pharmacy reviewers, all of whom interact with the system at different points in the medication lifecycle [16].

Pharmacists remain at the center of digital medication management. They validate prescriptions, manage inventory via automated systems, respond to CDSS alerts, and provide therapeutic recommendations through integrated dashboards. Their evolving responsibilities now also include interpreting analytics and contributing to population health interventions via digital platforms [17].

Prescribers, including physicians and nurse practitioners, use e-prescribing modules embedded within the EHR to initiate medication orders. Digital tools assist them in selecting formulary-approved medications, checking for contraindications, and adhering to clinical guidelines based on patient-specific data [18]. The integration of clinical pathways into these systems supports consistency in prescribing practices across departments and facilities.

Nurses, responsible for administering medications, interact with barcode medication administration (BCMA) tools and ADCs. These technologies ensure that the “five rights” of medication safety—right patient, drug, dose, time, and route—are systematically upheld [19]. Nurses also document real-time administration and patient responses into the EHR, completing the data feedback loop.

In remote or centralized review models, telepharmacy plays an expanding role. Pharmacists located offsite verify prescriptions, provide consultations, and monitor therapy through cloud-based platforms connected to the hospital's digital pharmacy infrastructure. This model increases accessibility, especially in rural or resource-limited settings [20].

Effective workflow design involves mapping these user interactions onto system capabilities to minimize redundancy, reduce alert fatigue, and ensure accountability. Role-specific access controls, task delegation, and escalation pathways are embedded into the system architecture to enhance safety and operational clarity [21].

As digital pharmacy systems continue to evolve, workflow alignment remains essential to achieving their full potential—delivering not only automation but also enhanced coordination, patient safety, and clinical insight across the healthcare continuum [22].

3. Medication error reduction: clinical and technical perspectives

3.1. Common Sources of Medication Errors

Medication errors occur at multiple points across the drug use process, with each stage vulnerable to specific risks. Four key phases—prescribing, transcription, dispensing, and administration—contribute significantly to error incidence, particularly in high-volume and high-acuity healthcare environments [9].

Prescribing errors are among the most frequent and impactful. These include incorrect drug selection, inappropriate dosing, and failure to consider allergies or contraindications. Contributing factors include incomplete patient information, inadequate access to clinical guidelines, and time pressures during consultations [10].

Transcription errors occur when medication orders are transferred manually between paper charts, electronic systems, or verbal communications. Errors at this stage can result from illegible handwriting, misunderstood abbreviations, or misinterpretation of verbal orders, especially in environments where standardized protocols are lacking [11].

Dispensing errors, which happen within the pharmacy, include incorrect medication preparation, mislabeling, and failure to verify medication identity. These mistakes may stem from look-alike/sound-alike (LASA) drugs, interruptions during workflow, or poor inventory management systems [12].

Administration errors are typically made by nurses or caregivers and include delivering the wrong drug, incorrect dosage, improper timing, or using the wrong route. Contributory factors include lack of bedside verification, poor documentation, and communication breakdowns between clinical teams [13].

Each of these errors not only jeopardizes patient safety but also incurs substantial financial costs due to adverse events, increased hospital stays, and potential litigation. Recognizing the specific vulnerabilities of each stage is essential for designing targeted digital interventions that minimize human error and enhance medication safety [14].

3.2. How Digital Platforms Prevent Errors

Digital health technologies have emerged as powerful tools in reducing medication errors across the entire prescribing-to-administration continuum. Platforms combining automation, data integration, and decision support offer systemic safeguards against both routine and catastrophic drug-related events [15].

Barcode scanning systems are particularly effective during dispensing and administration. By verifying medication identity, dosage, and patient association through barcode matching, these systems significantly reduce wrong-drug and wrong-patient errors. Barcode medication administration (BCMA) systems embedded into electronic health records (EHRs) help nurses confirm the “five rights” before administering any medication: right patient, drug, dose, time, and route [16].

Real-time alert systems powered by Clinical Decision Support Systems (CDSS) flag potential errors at the point of prescribing. These alerts range from drug–drug and drug–allergy interactions to dose range checks and therapeutic duplications. When appropriately calibrated, these systems can prevent critical incidents by intervening before the prescription is finalized [17].

In pharmacy settings, automated dispensing cabinets (ADCs) reduce the chances of dispensing the wrong medication by limiting access to only the drugs needed for a specific patient. These cabinets can be linked to real-time inventory systems and EHRs, ensuring traceability and accountability for every dispensed dose [18].

Computerized Provider Order Entry (CPOE) systems eliminate transcription errors by allowing prescribers to input orders directly into digital platforms. This bypasses the need for verbal or handwritten communications and standardizes medication entries with dropdown menus, structured order sets, and integrated reference data [19].

Pharmacists also benefit from clinical dashboards that consolidate medication profiles, lab data, and risk scores into a single interface. These tools enable medication therapy management and help identify issues such as renal dose adjustments, high-alert medication usage, or non-adherence risk [20].

Furthermore, real-time verification technologies enable remote pharmacists to review, approve, or flag prescriptions from any location. In telepharmacy models, this not only expands access but also introduces another verification layer, reducing errors in rural or after-hours settings [21].

Digital platforms must be carefully designed to avoid alert fatigue, overreliance on automation, and interface complexity. However, when implemented with workflow alignment and user training, they are proven to significantly enhance patient safety and operational efficiency in medication use [22].

Table 1 Summary of Reported Reductions in Medication Errors by Platform Type

Platform Type	Reported Reduction in Medication Errors (%)	Study/Setting	Primary Mechanism of Error Reduction
Barcode Medication Administration (BCMA)	50–58%	Multi-site U.S. hospitals	Real-time verification of patient-drug match
Computerized Provider Order Entry (CPOE)	45–55%	UK tertiary hospital	Standardized order sets and allergy/dose alerts
Automated Dispensing Cabinets (ADCs)	30–40%	Singapore regional hospitals	Controlled access and drug identification at point-of-use
Clinical Decision Support Systems (CDSS)	35–48%	Oncology and critical care units	Drug interaction, dose range, and duplication alerts
Telepharmacy Review Systems	39–50%	U.S. rural critical access hospitals	Remote verification and after-hours clinical oversight
E-Prescribing Platforms	25–35%	High-volume community pharmacies	Elimination of handwriting and transcription errors

3.3. Clinical Case Studies

Several real-world implementations of digital platforms have demonstrated measurable reductions in medication errors and associated adverse drug events (ADEs). These case studies highlight how different technologies—applied across diverse care settings—can drive significant improvements in patient safety and system performance.

In one multi-site U.S. health system, the integration of barcode scanning and BCMA technology led to a 58% reduction in administration-related errors within 12 months of implementation. Nurses were equipped with handheld scanners, and bedside terminals provided real-time verification prompts. This initiative was particularly impactful in intensive care and pediatric units, where dosing precision is critical [23].

At a tertiary hospital in the United Kingdom, the deployment of a CPOE system linked with CDSS reduced prescribing errors by 45%, especially in cardiovascular and oncology wards. Real-time alerts prompted clinicians to review dose appropriateness, renal function thresholds, and drug interactions. Importantly, the alert override rate was low due to well-calibrated algorithms and user-centered design [24].

A regional hospital network in Singapore implemented automated dispensing robots integrated with smart inventory systems. These robots performed tasks such as pill counting, labeling, and packaging. The error rate for dispensing dropped from 3.2% to 0.4% within six months, alongside a 30% increase in pharmacist time allocated to clinical tasks rather than manual preparation [25].

In telepharmacy settings, a study involving critical access hospitals in the U.S. Midwest showed that remote pharmacist order review systems reduced after-hours prescribing errors by 39%. Pharmacists stationed offsite accessed real-time EHRs, provided dosing consultations, and flagged high-alert drugs for in-person review the next morning [26].

Another example from Australia involved the integration of medication reconciliation tools within EHRs, which enabled pharmacists to verify discharge medications more effectively. The intervention led to a 28% decrease in readmissions linked to medication discrepancies within 30 days post-discharge [27].

These case studies underscore the scalability and versatility of digital interventions across a variety of care models. Regardless of setting, success hinged on stakeholder training, strong data governance, and continuous system evaluation. As such, they serve as evidence that technology, when well-aligned with workflow and clinical priorities, plays a pivotal role in preventing medication errors and promoting safer patient outcomes [28].

4. Economic evaluation methods and frameworks

4.1. Fundamentals of Health Economic Evaluation

Health economic evaluation offers a structured methodology to assess the value of healthcare interventions by comparing their costs and outcomes. Within the context of digital pharmacy platforms, such evaluations are essential for determining whether innovations like e-prescribing systems, barcode scanning, or clinical decision support provide sufficient value relative to their cost of implementation and maintenance [13].

The three most commonly applied methods in health economics include cost-effectiveness analysis (CEA), cost-benefit analysis (CBA), and budget impact analysis (BIA). In CEA, costs are compared with health outcomes measured in clinical units, such as adverse drug events (ADEs) avoided or medication errors reduced. This technique is particularly relevant in evaluating digital interventions aimed at improving safety and efficiency [14].

CBA, in contrast, translates both costs and benefits into monetary values, enabling a direct comparison of financial returns against investments. While more comprehensive, CBA can be limited by the complexity of assigning monetary values to clinical outcomes such as patient satisfaction or error prevention [15].

BIA examines the financial consequences of adopting a new intervention over a short-to-medium timeframe. It is particularly relevant to payers and hospital administrators who must forecast the effect of new technologies on operational budgets, workforce deployment, and medication expenditures [16].

Each method plays a complementary role in appraising digital pharmacy investments. Importantly, these evaluations must consider not only immediate savings but also long-term system impacts, such as reductions in hospital readmissions, litigation avoidance, and improvements in staff productivity [17]. This broader lens ensures that healthcare organizations adopt technologies not only based on cost minimization but also based on strategic value creation and outcome enhancement.

4.2. Measuring Direct and Indirect Costs

An accurate economic assessment of digital pharmacy tools must account for both direct and indirect costs. Direct costs typically include hardware and software expenses, implementation fees, licensing, training, and ongoing system maintenance. These are the most visible and often the easiest to quantify. However, failing to capture indirect costs and savings can significantly undervalue or overstate the economic impact of these interventions [18].

A significant direct cost often overlooked is medication waste, which occurs due to overstocking, mislabeling, or expiry. Digital inventory systems and automated dispensing units can minimize such inefficiencies, leading to tangible savings across large hospital networks [19]. By optimizing procurement patterns and tracking usage trends, these tools enable pharmacies to reduce surplus inventory and mitigate write-offs.

On the other hand, indirect costs such as time lost to workflow inefficiencies, staff rework, or delayed discharges due to pharmacy errors also contribute to the economic burden. These costs are less visible but cumulatively substantial. For example, when nurses spend excessive time clarifying prescriptions or searching for missing doses, their clinical productivity is compromised [20]. Likewise, when pharmacists must manually transcribe or verify orders, the risk of burnout and overtime increases—both of which have downstream financial implications.

Adverse drug events (ADEs) represent a particularly significant cost driver. Even minor events, such as nausea or dizziness from medication errors, can lead to additional diagnostic tests, follow-up visits, or extended hospital stays. More severe ADEs may involve intensive care admissions, legal action, or patient mortality, all of which carry profound economic and ethical implications [21].

A comprehensive evaluation must consider cost offsets—for instance, the investment in barcode scanning may be justified by the prevention of high-cost ADEs or malpractice claims. Therefore, health systems must develop models that

holistically capture the full financial impact of digital pharmacy integration, from procurement to patient discharge and beyond [22].

4.3. Data Collection and Modeling Approaches

Conducting robust economic evaluations of digital pharmacy interventions requires sophisticated data collection methods and analytical modeling tools. These approaches must align with the realities of healthcare delivery, offering transparency, reproducibility, and adaptability across different health system contexts [23].

One widely applied approach is Time-Driven Activity-Based Costing (TDABC). Unlike traditional costing models, TDABC assigns costs based on the actual time healthcare staff spend performing specific tasks, multiplied by their cost per minute. This method is particularly effective for mapping complex workflows in digital pharmacy systems—such as order verification, compounding, and delivery—and for identifying inefficiencies that can be addressed by automation [24]. By using process maps and observational data, TDABC models help quantify productivity gains from digital interventions in a highly granular manner.

Markov models are commonly used in cost-utility and cost-effectiveness analyses, especially when evaluating long-term outcomes such as ADE prevention or improved adherence from medication reminders. These models divide patient pathways into health states—such as "no error," "minor ADE," "severe ADE," and "death"—with transition probabilities based on clinical data. Over time, they simulate the costs and outcomes associated with digital pharmacy tools compared to standard practice [25].

Return on Investment (ROI) calculators offer a more business-oriented approach. These tools compare upfront costs against estimated savings and revenue enhancements over time, often factoring in avoided ADEs, reduced staffing needs, or fewer regulatory penalties. While ROI models are simpler than CEA or Markov models, they remain influential in decision-making, especially at the administrative level [26].

Accurate modeling requires high-quality, multi-source data. **Electronic health records (EHRs)**, pharmacy dispensing logs, staff time surveys, and financial reports all serve as vital inputs. Increasingly, health systems are integrating **data visualization tools** to track medication safety indicators in real-time, allowing for more agile and continuous economic assessment [27].

Table 2 Comparison of Economic Evaluation Techniques Used in Digital Pharmacy Studies

Evaluation Technique	Primary Focus	Strengths	Limitations	Common Use Cases
Cost-Effectiveness Analysis (CEA)	Cost per clinical unit (e.g., errors avoided)	Easy to compare interventions using natural health units	Does not factor in patient quality of life	Barcode scanning, decision support implementation
Cost-Utility Analysis (CUA)	Cost per QALY (Quality-Adjusted Life Year)	Incorporates both quality and length of life	Requires utility measurements, complex modeling	Adverse drug event prevention, patient monitoring
Cost-Benefit Analysis (CBA)	Converts both cost and benefit into monetary terms	Broad financial assessment, useful for ROI discussions	Difficult to assign monetary values to outcomes	Large-scale automation or robotics justification
Budget Impact Analysis (BIA)	Short- to medium-term affordability	Useful for payer decision-making and operational planning	Does not assess long-term outcomes or cost-effectiveness	Telepharmacy programs, software licensing decisions
Return on Investment (ROI)	Ratio of net savings to cost of investment	Easy to understand for stakeholders and administrators	Lacks clinical nuance, often ignores patient-centered outcomes	Automation tools, inventory optimization
Time-Driven Activity-Based Costing (TDABC)	Time and cost per task/process	Captures workflow efficiency, detailed operational insights	Resource-intensive, requires observational and time data	Staff reallocation, dispensing process redesign

To ensure validity and credibility, economic models should undergo sensitivity analysis, which tests the robustness of findings by varying input assumptions—such as medication error rates, staff salaries, or ADE treatment costs. This step is crucial for accounting for uncertainty and making informed decisions in dynamic healthcare environments [28].

Importantly, modeling outputs must be interpreted within the local policy and reimbursement context. For example, a technology that reduces errors may demonstrate strong ROI in countries with high malpractice costs but may be less financially compelling in low-resource settings unless paired with quality-based incentive programs [29].

Thus, successful economic evaluation of digital pharmacy tools requires both technical rigor and contextual nuance. Pharmacists, health economists, and clinical informatics teams must collaborate in designing models that accurately reflect operational realities while guiding scalable and sustainable innovation [30].

5. Evidence from real-world implementations

5.1. Hospital Pharmacy Systems

Hospital pharmacy systems have undergone significant transformation through digitalization, leading to improved operational efficiency, reduced medication errors, and enhanced clinical outcomes. These systems, which include computerized provider order entry (CPOE), automated dispensing cabinets (ADCs), and clinical decision support systems (CDSS), play a crucial role in managing the complexity of medication workflows in acute care settings [17].

From an economic perspective, hospitals that have implemented integrated digital pharmacy platforms report measurable cost reductions. For instance, automation has streamlined drug dispensing and inventory control, reducing labor requirements and medication waste. Studies have shown that hospitals using ADCs experienced inventory cost savings of up to 23% within the first year due to improved real-time tracking and automated restocking protocols [18].

In addition, CDSS embedded in hospital EHRs has helped prevent adverse drug events (ADEs), which are among the most costly and preventable outcomes of pharmacotherapy. Each prevented ADE can save a hospital an estimated $2,000–$8,000, depending on severity and required intervention [19]. These savings extend beyond direct treatment costs, contributing to shorter lengths of stay and avoidance of penalties linked to readmissions or safety lapses.

Hospitals also benefit from enhanced regulatory compliance. Digitally supported medication tracking aids in documentation for audits, reduces the likelihood of diversion, and meets safety standards mandated by accreditation bodies. Over time, this contributes to institutional reputability and funding eligibility [20].

Clinical outcomes have similarly improved. Digital systems support dose accuracy, allergy alerts, and renal adjustments, reducing human error at critical decision points. The result is a safer, more coordinated medication process that aligns with the goals of value-based care while simultaneously containing costs [21].

5.2. Community and Retail Pharmacy Platforms

Community and retail pharmacies are vital touchpoints in the continuum of care, and their digital evolution has significant implications for economic sustainability and medication safety. Tools such as e-prescribing interfaces, point-of-sale integration, real-time drug utilization reviews, and mobile refill systems are now standard in many retail chains and independent pharmacies [22].

From a cost-efficiency perspective, digital platforms reduce the reliance on manual tasks, allowing pharmacies to operate with leaner staff while improving accuracy. For example, automated refill reminder systems reduce no-show rates and increase prescription adherence, contributing to higher medication possession ratios and reducing chronic disease complications downstream [23].

The integration of real-time benefit tools (RTBTs) enables pharmacists to access patient-specific insurance coverage and out-of-pocket costs before dispensing, helping patients choose affordable alternatives. This improves transparency and encourages prescription pick-up, thus reducing the economic losses associated with abandoned prescriptions, which cost U.S. pharmacies over $300 million annually [24].

Digital platforms also enable pharmacies to participate in clinical programs, such as medication therapy management (MTM) and immunization tracking. These services not only generate alternative revenue streams but also contribute to

value-based care contracts that reward pharmacies for improving patient outcomes. Pharmacists can identify gaps in care, initiate interventions, and document outcomes electronically, aligning with payer expectations [25].

Error reduction in retail settings has also been notable. E-prescribing minimizes transcription errors from handwritten prescriptions, while barcode scanning during dispensing ensures correct drug identification. Studies suggest that the use of integrated dispensing software with alert systems can reduce dispensing errors by up to 40% in high-volume pharmacies [26].

Retail pharmacy chains investing in digital infrastructure also gain operational resilience, especially during disruptions like the COVID-19 pandemic. Digital workflows allowed many pharmacies to scale services such as drive-through pickup, mail-order dispensing, and remote consultations, maintaining service continuity while limiting in-person contact [27].

Ultimately, the digitalization of community pharmacy practice contributes to a more cost-effective, accurate, and patient-centered model, enhancing both commercial sustainability and public health outcomes in local populations [28].

5.3. Telepharmacy in Rural and Underserved Areas

Telepharmacy—the provision of pharmaceutical care via telecommunications—has emerged as a scalable solution to workforce shortages, geographic barriers, and limited access to care in rural and underserved regions. By connecting central pharmacists to remote dispensing sites, hospitals, and clinics, telepharmacy ensures medication oversight, regulatory compliance, and clinical support in areas where on-site pharmacists are scarce [29].

Economically, telepharmacy enables rural hospitals and clinics to operate without incurring the full cost of staffing an on-site pharmacist. A typical rural telepharmacy model saves approximately $150,000–$200,000 annually in staffing costs while maintaining full pharmaceutical service availability. These savings are crucial for facilities operating on tight budgets or serving low-income populations [30].

Telepharmacy also contributes to error reduction and medication safety in isolated regions. Pharmacists remotely verify prescriptions, monitor automated dispensing, and provide consultation before administration. Studies have shown that remote verification reduces medication errors in rural facilities by 35%–50%, making it comparable in safety to traditional models [31].

In terms of workforce optimization, telepharmacy maximizes the capacity of licensed pharmacists. One pharmacist can oversee multiple remote sites, conduct therapy reviews, and participate in multidisciplinary care planning from a centralized location. This enhances efficiency while maintaining compliance with practice regulations and licensure requirements [32].

Moreover, telepharmacy expands access to services such as medication therapy management, anticoagulation monitoring, and chronic disease counseling. In regions with high burdens of diabetes or cardiovascular disease, remote pharmacists can intervene early, improving outcomes and reducing costly hospitalizations [33].

Policy support has also played a role in expanding telepharmacy services. Several U.S. states have updated pharmacy practice laws to accommodate remote verification and virtual consultation, increasing the reach of pharmaceutical care into previously unserved regions [34]. Internationally, countries such as Australia, Canada, and India have begun to adopt similar models, particularly in First Nations, tribal, and remote island communities [35].

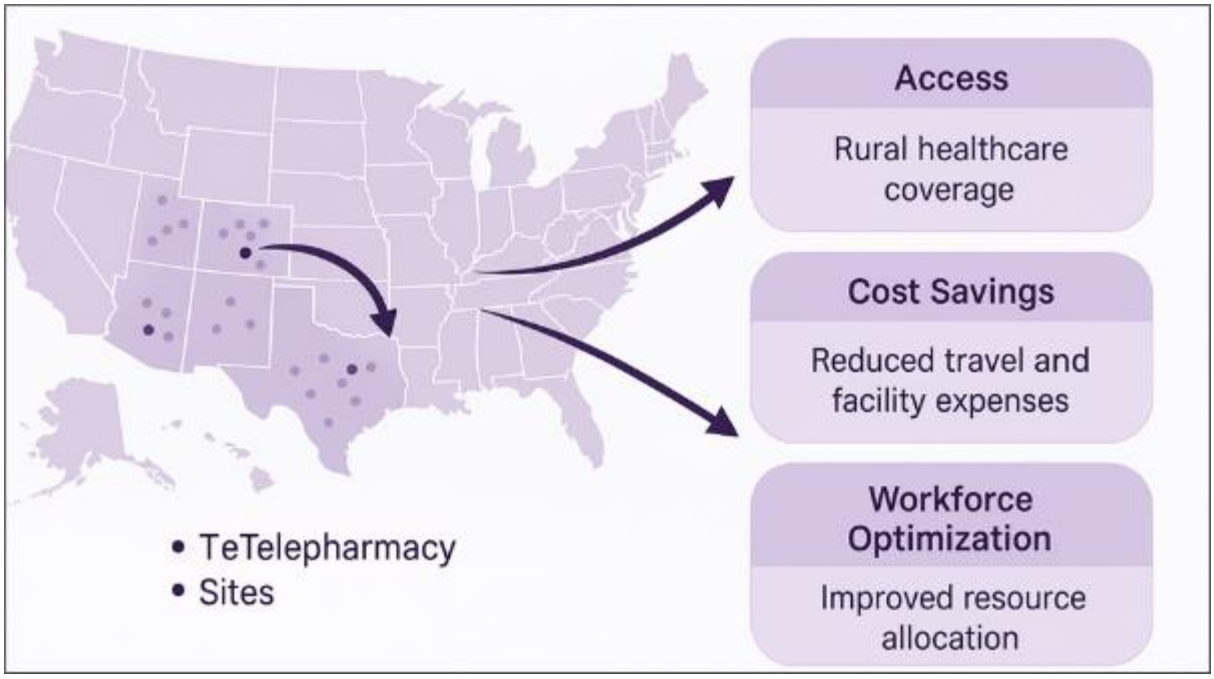

Figure 2 Map of Telepharmacy Expansion and Economic Outcomes in Rural Networks

The return on investment for telepharmacy goes beyond cost savings. By reducing medication errors, improving chronic disease management, and ensuring continuity of care, it addresses critical **health equity gaps**. It also empowers pharmacists to function at the top of their license, fulfilling clinical roles that would otherwise be left vacant due to logistical constraints [36].

As health systems increasingly focus on equitable access and sustainable care models, telepharmacy stands out as a transformative tool with both clinical and economic benefits in areas most in need [37].

6. Cost-saving drivers and productivity gains

6.1. Human Resource Efficiency

One of the most immediate and visible impacts of digital pharmacy transformation is the improvement in human resource efficiency. Pharmacists, pharmacy technicians, and support staff can redirect their time from repetitive, manual tasks toward more strategic and clinical functions. This reallocation improves care quality and workforce satisfaction while reducing operational strain [21].

Digital tools such as automated dispensing systems, barcode verification, and prescription scanning software automate time-consuming processes like drug counting, labeling, and verification. A study from a U.S.-based hospital network reported that pharmacists saved an average of 2.5 hours per shift after implementing a centralized robotic dispensing unit, time that was reinvested in clinical rounds and patient counseling [22].

Additionally, task automation reduces the dependency on temporary or overtime staffing during peak workloads. In high-throughput environments such as oncology or emergency departments, automation ensures uninterrupted workflows with minimal staffing fluctuations. This reliability translates to lower staffing costs and better scheduling predictability [23].

Importantly, automation improves safety by reducing fatigue-related errors. Pharmacy staff no longer need to manually check every dose or transcribe every order, lowering cognitive load and risk exposure. This has significant legal and regulatory implications, especially in jurisdictions with strict reporting and liability frameworks [24].

Further downstream, workflow efficiency reduces task redundancy. For instance, integrated order entry systems prevent multiple staff members from checking the same prescription, while real-time dashboards allow for better coordination and workload distribution [25]. When properly aligned with user training and role design, these digital

efficiencies allow institutions to derive greater value from existing staff while maintaining high standards of safety and compliance.

6.2. Inventory and Supply Chain Optimization

Digital pharmacy platforms also transform inventory and supply chain management, a historically labor-intensive and error-prone function. Traditional inventory practices often rely on periodic manual counts, reactive restocking, and opaque procurement chains—all of which contribute to overstocking, stockouts, and financial waste [26].

Through real-time stock monitoring and predictive analytics, pharmacy information systems now enable demand forecasting, automated restocking, and accurate tracking of inventory levels. These tools integrate with purchasing systems, allowing just-in-time delivery and minimizing the need for large buffer stocks. Studies show that hospitals using digital inventory systems reduced drug holding costs by 18%–25% within one year of implementation [27].

Barcode-based tracking systems improve accountability by assigning each drug unit a unique identifier, linking it to patient orders and reducing the risk of diversion or misplacement. This enhances visibility throughout the supply chain—from vendor delivery through storage, dispensing, and patient administration [28].

Another key advantage is expiry date monitoring, which ensures that drugs nearing expiration are flagged for prioritized use, return, or redistribution. Such controls minimize wastage due to expired stock, a major cost driver in poorly managed pharmacy departments [29].

Moreover, predictive algorithms analyze usage trends across departments or seasons, enabling proactive procurement planning. For instance, higher demand for antipyretics during flu season or increased insulin use in endocrinology clinics can be forecasted and accommodated through early ordering and stock redistribution [30].

These inventory optimizations not only reduce procurement and holding costs but also enhance service continuity, ensuring critical medications are available exactly when and where they are needed—maximizing both clinical impact and operational efficiency [31].

6.3. Administrative and Documentation Savings

Table 3 Economic Impact Metrics of Digitized Pharmacy Operations Across Institutions

Institution Type	Key Digital Tools Implemented	Economic Metric	Reported Impact
Urban Tertiary Hospital	Automated Dispensing, Barcode Verification, CDSS	Medication Error Reduction	↓ 55% in administration-related errors
Community Retail Pharmacy	E-prescribing, Refill Apps, POS Integration	Prescription Abandonment Rate	↓ 30% abandonment; ↑ 22% pickup compliance
Rural Critical Access Hospital	Telepharmacy, Remote Verification, Inventory Dashboards	Staffing Cost Savings	↓ $180,000 annually in pharmacist salaries
Regional Health System	EHR-CDSS Integration, Smart Inventory, CPOE	Drug Waste Reduction	↓ 25% in expired/unused medications
National Pharmacy Chain	AI Refill Prediction, Centralized Robotic Fulfillment	Dispensing Efficiency	↑ 35% script fill rate per pharmacist per day
Academic Medical Center	Pharmacogenomics CDSS, Decision Dashboards	ADE-Related Cost Avoidance	$1.2M saved annually through error prevention

Administrative burdens in pharmacy operations can significantly strain institutional budgets and staff morale. Paper-based workflows, redundant documentation, and disjointed communication channels have long contributed to delays, inaccuracies, and overhead expenses. Digital transformation mitigates these challenges by streamlining administrative and documentation tasks, thereby improving both efficiency and compliance [32].

One of the primary savings comes from electronic documentation systems, which replace handwritten logs, physical records, and faxed communications. Electronic medication administration records (eMARs), for example, allow real-

time tracking of drug delivery, enabling pharmacists and nurses to collaborate seamlessly without needing to manually update paper charts [33].

Integrated claims and billing platforms also contribute significantly to administrative efficiency. With digital prescriptions automatically coded and linked to insurance databases, reimbursement processing becomes faster and more accurate. This reduces the frequency of claim denials and rework, which, in some healthcare systems, can account for up to 20% of pharmacy billing overhead [34].

Another key benefit is the reduction of data entry duplication. When EHRs, pharmacy systems, and supply chain platforms are interoperable, staff no longer need to enter the same information in multiple systems. This not only saves time but also reduces the likelihood of errors during data transcription, a common source of documentation inconsistencies and audit flags [35].

Digitally documented workflows also support regulatory audits and quality assurance. Automated logs can be pulled instantly to demonstrate compliance with medication safety protocols, inventory accuracy, and staff accountability. This reduces the labor required during inspections and enhances the institution's preparedness for accreditation [36].

Collectively, these administrative efficiencies free up resources that can be redirected toward clinical care or reinvested in system upgrades. Over time, they contribute to a leaner, faster, and more resilient pharmacy operation, well-aligned with the cost-saving goals of value-based healthcare models [37].

7. Policy, regulation, and reimbursement considerations

7.1. Regulatory Standards for Digital Platforms

Digital pharmacy platforms are subject to a complex array of **regulatory frameworks** that ensure their safety, security, and effectiveness. In the United States, the **Food and Drug Administration (FDA)** oversees digital health technologies that qualify as medical devices, including certain clinical decision support systems and software used for drug dosing and interaction alerts. Tools that influence clinical decision-making must comply with the FDA's Software as a Medical Device (SaMD) guidance, which requires evidence of reliability, validation, and risk mitigation [25].

In the European Union, the European Medicines Agency (EMA) works alongside national regulatory bodies to oversee software that interacts with medicinal products. The Medical Device Regulation (MDR), enforced since 2021, requires rigorous conformity assessments for digital tools classified as medical devices, including some pharmacy automation systems [26].

Data protection is equally important. In the U.S., compliance with the Health Insurance Portability and Accountability Act (HIPAA) is mandatory for any digital platform handling protected health information (PHI). HIPAA requires stringent safeguards related to access control, data encryption, audit trails, and breach notification protocols [27].

Globally, many institutions also adhere to ISO/IEC standards such as ISO 27799 (health information security management) and ISO 13485 (medical device quality management systems). These frameworks provide additional quality assurance benchmarks and are often prerequisites for international implementation [28].

As digital pharmacy tools continue to evolve, maintaining regulatory compliance is critical—not only for legal protection but also for clinical safety, data governance, and stakeholder trust. Developers and health institutions must work closely with legal teams and regulatory consultants to ensure ongoing alignment with domestic and international standards [29].

7.2. Reimbursement Pathways and Value-Based Alignment

Despite the growing adoption of digital pharmacy technologies, reimbursement frameworks for these tools remain fragmented and underdeveloped in many healthcare systems. Traditional fee-for-service models are often ill-equipped to capture the long-term cost savings and quality improvements enabled by digital platforms, leading to underinvestment in these innovations [30].

In response, several payers are experimenting with digital health reimbursement models, including per-member-per-month (PMPM) fees, shared savings contracts, and outcome-based incentive programs. In the U.S., Medicare Advantage

and some Medicaid Managed Care Organizations now provide limited reimbursement for telepharmacy services, medication therapy management (MTM), and remote clinical monitoring facilitated by digital platforms [31].

Some commercial insurers are also adopting value-based pharmacy contracts, which tie reimbursement to measurable outcomes such as medication adherence, reduction in adverse drug events, or achievement of clinical benchmarks (e.g., A1C control in diabetes patients). Pharmacists participating in such contracts must document interventions and outcomes digitally to validate performance and secure reimbursement [32].

In Europe, countries like Germany and France have introduced formal digital health application reimbursement pathways, where certified tools can be listed for national insurance coverage. However, these are still primarily directed at patient-facing applications and rarely extend to back-end pharmacy systems [33].

To expand access and incentivize innovation, policymakers and payer organizations must establish standardized reimbursement pathways that recognize the full economic value of digital pharmacy tools. This includes accounting for operational savings, quality improvements, and enhanced patient engagement—all of which align with broader **value-based care objectives** [34].

7.3. Legal, Ethical, and Equity Considerations

The digital transformation of pharmacy also raises important legal, ethical, and equity concerns. One of the primary issues is data ownership—who controls and has access to the vast amount of health and behavioral data generated by digital platforms. Without clear policies, data may be used for secondary purposes without patient consent, raising privacy concerns and ethical dilemmas [35].

Informed patient consent is essential, particularly when integrating AI-based decision support systems or sharing data across institutions. Transparent data practices, opt-in models, and clear communication are critical to building trust and ensuring compliance with ethical standards [36].

Equity remains a significant challenge. Rural and underserved populations may lack access to high-speed internet, reliable hardware, or trained personnel required to operate digital platforms effectively. Without proactive inclusion strategies, the digital divide could widen existing health disparities [37].

Policies must therefore address not only compliance but also accessibility, cultural sensitivity, and social inclusion. Funding rural broadband, subsidizing digital tools, and training local providers are among the steps needed to ensure that the benefits of digital pharmacy are distributed equitably across all populations [38].

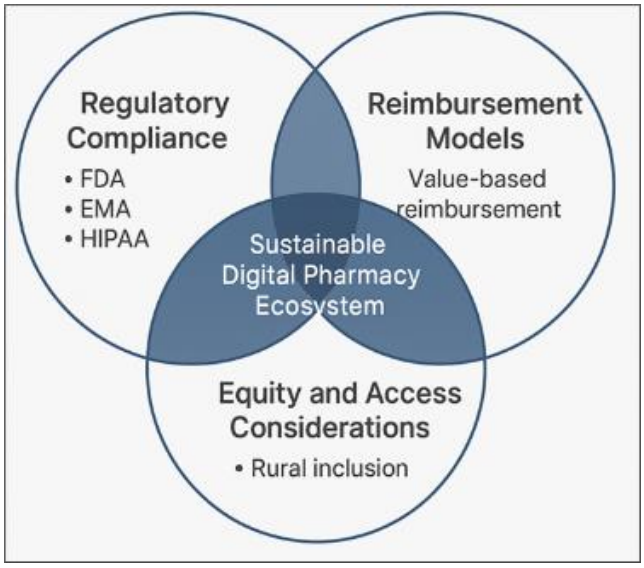

Figure 3 Regulatory, Reimbursement, and Equity Framework for Digital Pharmacy Implementation

8. Challenges, limitations, and future directions

8.1. Technical Barriers and Integration Complexity

Despite the demonstrated benefits of digital pharmacy platforms, health systems continue to face substantial technical barriers to seamless implementation and scale. One of the most persistent issues is the reliance on legacy systems—older pharmacy information systems and hospital infrastructure that lack compatibility with modern software tools. These outdated platforms often require custom interfaces or middleware for integration, adding to the cost and complexity of implementation [29].

Interoperability gaps remain a critical challenge. Many digital pharmacy tools are developed by different vendors, each using proprietary data structures and access protocols. This fragmentation impedes the smooth flow of information across electronic health records (EHRs), inventory systems, and claims processing platforms. For example, a dispensing system that cannot communicate with a hospital's EHR may force duplicate documentation or manual reconciliation of medication orders, increasing the risk of error and inefficiency [30].

Compounding these issues is the lack of standardization in application programming interfaces (APIs), vocabulary coding (e.g., SNOMED CT, RxNorm), and data exchange protocols. Even when standards like HL7 FHIR are used, inconsistent implementation across vendors can disrupt real-time data synchronization and reduce system usability [31].

Healthcare institutions must also consider cybersecurity and IT capacity. As digital platforms handle sensitive patient data, robust encryption, identity management, and backup systems are required. However, not all facilities—particularly in low-resource or rural settings—have the infrastructure or skilled personnel to maintain these systems reliably [32].

Overcoming these barriers requires investment in scalable, standards-based systems, cross-vendor collaboration, and coordinated policy efforts aimed at promoting technical interoperability and long-term platform evolution.

8.2. Limitations in Economic Measurement

While economic evaluations of digital pharmacy tools are gaining traction, significant methodological limitations hinder their accuracy and generalizability. One of the foremost challenges is data quality. Many institutions rely on fragmented data sources, incomplete patient records, or outdated inventory logs, leading to skewed estimates of cost savings and intervention effectiveness [33].

Another issue is the time horizon used in modeling. Short-term economic evaluations may capture immediate savings (e.g., reduced dispensing time), but they often fail to reflect long-term outcomes such as avoided hospital readmissions, improved adherence, or population health improvements. These downstream effects require multi-year modeling and validated assumptions that are often difficult to substantiate with available data [34].

Economic modeling also struggles to quantify indirect benefits, such as reduced staff stress, improved patient satisfaction, or fewer medication-related lawsuits. These variables are difficult to measure, yet they significantly contribute to organizational sustainability and risk mitigation [35].

Moreover, variations in local pricing, workforce costs, and regulatory environments can limit the transferability of economic evaluations across settings. A technology that yields strong returns in a high-income urban hospital may not demonstrate the same value in a rural community clinic.

To address these limitations, future evaluations must leverage real-world data (RWD) from EHRs, pharmacy databases, and patient-reported outcomes to build dynamic, adaptable models. Sensitivity analysis, probabilistic modeling, and stakeholder consultation should also be standard components of comprehensive economic assessments [36].

8.3. Future Research and Innovation Opportunities

As digital pharmacy systems evolve, several **emerging technologies** and research domains present opportunities for further innovation. Artificial Intelligence (AI) remains a transformative force, with the potential to support predictive analytics, autonomous verification, and advanced medication error detection. AI-powered decision support systems can prioritize alerts based on clinical context, reducing fatigue while improving safety [37].

Another promising frontier is blockchain technology, which offers a secure, decentralized ledger for tracking medication transactions, preventing counterfeiting, and enhancing data integrity. When integrated with supply chain systems, blockchain can improve transparency and traceability across the entire medication lifecycle [38].

Patient-centered platforms are also gaining momentum. These include mobile apps for medication reminders, chatbots for education, and personalized dashboards that allow patients to track adherence and communicate directly with pharmacists. Such platforms promote engagement, health literacy, and shared decision-making—core principles of modern, value-based care [39].

Future research should also explore the integration of social determinants of health (SDOH) into pharmacy analytics, enabling more equitable service delivery. Additionally, the impact of digital tools on workforce dynamics, environmental sustainability, and global health equity remains underexplored and ripe for academic inquiry.

Together, these innovations can expand the scope, inclusivity, and effectiveness of digital pharmacy, setting the stage for a safer, smarter, and more sustainable medication ecosystem.

9. Conclusion

The digital transformation of pharmacy operations presents a pivotal opportunity to redefine medication safety, clinical efficiency, and economic sustainability in healthcare systems worldwide. This review has highlighted how digital pharmacy platforms—ranging from e-prescribing systems and automated dispensing cabinets to clinical decision support tools and telepharmacy services—offer substantial benefits in operational performance, workforce optimization, and patient outcomes.

Key findings reveal that these technologies not only reduce medication errors across prescribing, dispensing, and administration stages but also lead to measurable cost savings through reduced adverse drug events, improved inventory control, and minimized administrative burdens. Hospitals, community pharmacies, and rural telepharmacy sites alike have reported improvements in patient safety metrics, medication adherence, and staff productivity following the adoption of integrated digital platforms.

However, the successful deployment of digital pharmacy systems is not without challenges. Technical barriers such as interoperability gaps, legacy systems, and cybersecurity risks remain significant obstacles. Equally, economic evaluations are often constrained by limitations in data quality, modeling assumptions, and variability in healthcare contexts. Nonetheless, the benefits outweigh the barriers, particularly when digital tools are implemented strategically and supported by policy frameworks.

To capitalize on the full potential of digital pharmacy systems, stakeholders across the healthcare ecosystem must adopt a coordinated approach:

- Health system leaders should prioritize investments in interoperable, standards-based digital infrastructure that aligns with clinical workflows and enhances pharmacist capabilities.
- Policymakers and regulators must establish clear reimbursement pathways for digital pharmacy services, including telepharmacy, clinical decision support, and remote medication management.
- Payers and insurers should adopt value-based payment models that reward measurable outcomes such as error reduction, adherence improvement, and cost avoidance.
- Pharmacists and health informatics professionals should be actively involved in the design, implementation, and evaluation of digital tools to ensure clinical relevance and usability.

Looking ahead, the vision for digital pharmacy must be one that is not only technologically advanced but also economically and socially sustainable. This includes integrating emerging innovations such as artificial intelligence, blockchain, and patient-centered mobile platforms, while ensuring equitable access across geographic and demographic lines. Data privacy, patient engagement, and workforce development must also remain at the forefront of system design.

Ultimately, an economically sustainable digital pharmacy ecosystem is one that improves health outcomes, reduces avoidable costs, and empowers healthcare professionals to deliver safer, smarter, and more personalized care. By aligning innovation with strategic investment and inclusive policy, the future of pharmacy practice can be reimagined to meet the evolving needs of 21st-century healthcare.

References

[1] O'Reilly D, Tarride JE, Goeree R, Lokker C, McKibbon KA. The economics of health information technology in medication management: a systematic review of economic evaluations. Journal of the American Medical Informatics Association. 2012 May 1;19(3):423-38.

[2] Guchelaar HJ, Colen HB, Kalmeijer MD, Hudson PT, Teepe-Twiss IM. Medication errors: hospital pharmacist perspective. Drugs. 2005 Sep;65:1735-46.

[3] Ojeleye O, Avery A, Gupta V, Boyd M. The evidence for the effectiveness of safety alerts in electronic patient medication record systems at the point of pharmacy order entry: a systematic review. BMC medical informatics and decision making. 2013 Dec;13:1-0.

[4] Calloway S, Akilo HA, Bierman K. Impact of a clinical decision support system on pharmacy clinical interventions, documentation efforts, and costs. Hospital pharmacy. 2013 Sep;48(9):744-52.

[5] Kuperman GJ, Gibson RF. Computer physician order entry: benefits, costs, and issues. Annals of internal medicine. 2003 Jul 1;139(1):31-9.

[6] Senbekov M, Saliev T, Bukeyeva Z, Almabayeva A, Zhanaliyeva M, Aitenova N, Toishibekov Y, Fakhradiyev I. The recent progress and applications of digital technologies in healthcare: a review. International journal of telemedicine and applications. 2020;2020(1):8830200.

[7] Kumar S, Steinebach M. Eliminating US hospital medical errors. International Journal of Health Care Quality Assurance. 2008 Jul 18;21(5):444-71.

[8] Lu YC, Xiao Y, Sears A, Jacko JA. A review and a framework of handheld computer adoption in healthcare. International journal of medical informatics. 2005 Jun 1;74(5):409-22.

[9] Yussuf MF, Oladokun P, Williams M. Enhancing cybersecurity risk assessment in digital finance through advanced machine learning algorithms. Int J Comput Appl Technol Res. 2020;9(6):217-235. Available from: https://doi.org/10.7753/ijcatr0906.1005

[10] Umeaduma CMG. Evaluating company performance: the role of EBITDA as a key financial metric. Int J Comput Appl Technol Res. 2020;9(12):336–49. doi:10.7753/IJCATR0912.10051.

[11] Cazin JL, Gosselin P. Implementing a multiple-isolator unit for centralized preparation of cytotoxic drugs in a cancer center pharmacy. Pharmacy World and Science. 1999 Aug;21:177-83.

[12] Bates DW, Cohen M, Leape LL, Overhage JM, Shabot MM, Sheridan T. Reducing the frequency of errors in medicine using information technology. Journal of the American Medical Informatics Association. 2001 Jul 1;8(4):299-308.

[13] Balfour DC, Evans S, Januska J, Lee HY, Lewis SJ, Nolan SR, Noga M, Stemple C, Thapar K. Health information technology—results from a roundtable discussion. Journal of managed care pharmacy. 2009 Jan;15(1 Supp A):10-7.

[14] Glick HA, Doshi JA, Sonnad SS, Polsky D. Economic evaluation in clinical trials. OUP Oxford; 2014 Oct 2.

[15] Genesis IO. Integrative pharmacoeconomics: redefining pharmacists' role in formulary design and value-based healthcare systems. Int J Comput Appl Technol Res. 2018;7(12):435–48. Available from: https://ijcat.com/archieve/volume7/issue12/ijcatr07121007.pdf. DOI: 10.7753/IJCATR0712.1007

[16] Hydari MZ, Telang R, Marella WM. Saving patient Ryan—can advanced electronic medical records make patient care safer?. Management Science. 2019 May;65(5):2041-59.

[17] Rejeb A, Bell L. Potentials of blockchain for healthcare: Case of Tunisia. Available at SSRN 3475246. 2019 Jul 25.

[18] Olayinka OH. Data driven customer segmentation and personalization strategies in modern business intelligence frameworks. World Journal of Advanced Research and Reviews. 2021;12(3):711-726. doi: https://doi.org/10.30574/wjarr.2021.12.3.0658

[19] Zare Mehrjerdi Y. RFID-enabled healthcare systems: risk-benefit analysis. International Journal of Pharmaceutical and Healthcare Marketing. 2010 Sep 7;4(3):282-300.

[20] Berenguer BB, La Casa CB, de La Matta MJ, Martin-Calero MJ. Pharmaceutical care: past, present and future. Current pharmaceutical design. 2004 Dec 1;10(31):3931-46.

[21] Helms MM, Moore R, Ahmadi M. Information technology (IT) and the healthcare industry: A SWOT analysis. International Journal of Healthcare Information Systems and Informatics (IJHISI). 2008 Jan 1;3(1):75-92.

[22] Petropoulou SG, Bekakos MP, Gravvanis GA. E-prescribing-Telepharmacy. In7th Hellenic European Conference on Computers 2005 Sep (pp. 22-25).

[23] Hillestad R, Bigelow J, Bower A, Girosi F, Meili R, Scoville R, Taylor R. Can electronic medical record systems transform health care? Potential health benefits, savings, and costs. Health affairs. 2005 Sep;24(5):1103-17.

[24] Olayinka OH. Big data integration and real-time analytics for enhancing operational efficiency and market responsiveness. Int J Sci Res Arch. 2021;4(1):280–96. Available from: https://doi.org/10.30574/ijsra.2021.4.1.0179

[25] Atasoy H, Greenwood BN, McCullough JS. The digitization of patient care: a review of the effects of electronic health records on health care quality and utilization. Annual review of public health. 2019 Apr 1;40(1):487-500.

[26] Castaneda C, Nalley K, Mannion C, Bhattacharyya P, Blake P, Pecora A, Goy A, Suh KS. Clinical decision support systems for improving diagnostic accuracy and achieving precision medicine. Journal of clinical bioinformatics. 2015 Dec;5:1-6.

[27] Johnson KB, Lehmann CU, Council on Clinical Information Technology, Del Beccaro MA, Alexander G, Drummond WH, Francis AB, Handler EG, Johnson TD, Kim GR, Leu M. Electronic prescribing in pediatrics: toward safer and more effective medication management. Pediatrics. 2013 Apr 1;131(4):e1350-6.

[28] Hauck K, Morton A, Chalkidou K, Chi YL, Culyer A, Levin C, Meacock R, Over M, Thomas R, Vassall A, Verguet S. How can we evaluate the cost-effectiveness of health system strengthening? A typology and illustrations. Social science & medicine. 2019 Jan 1;220:141-9.

[29] Slawomirski L, Auraaen A, Klazinga N. The economics of patient safety. Paris: Organisation for Economic Co-operation and Development. 2017 Mar.

[30] López-Martínez F, Núñez-Valdez ER, García-Díaz V, Bursac Z. A case study for a big data and machine learning platform to improve medical decision support in population health management. Algorithms. 2020 Apr 23;13(4):102.

[31] Mackey TK, Nayyar G. A review of existing and emerging digital technologies to combat the global trade in fake medicines. Expert opinion on drug safety. 2017 May 4;16(5):587-602.

[32] Dayer L, Heldenbrand S, Anderson P, Gubbins PO, Martin BC. Smartphone medication adherence apps: potential benefits to patients and providers. Journal of the American Pharmacists Association. 2013 Mar 1;53(2):172-81.

[33] Lapão LV. The future of healthcare: the impact of digitalization on healthcare services performance. InThe internet and health in Brazil: Challenges and trends 2018 Oct 25 (pp. 435-449). Cham: Springer International Publishing.

[34] Kolasa K, Kozinski G. How to value digital health interventions? A systematic literature review. International Journal of Environmental Research and Public Health. 2020 Jan;17(6):2119.

[35] Mackey TK, Nayyar G. Digital danger: a review of the global public health, patient safety and cybersecurity threats posed by illicit online pharmacies. British medical bulletin. 2016 Jun 1;118(1):110-26.

[36] Eskew JA, Jacobi J, Buss WF, Warhurst HM, Debord CL. Using innovative technologies to set new safety standards for the infusion of intravenous medications. Hospital Pharmacy. 2002 Nov;37(11):1179-89.

[37] Black C, Clar C, Henderson R, MacEachern C, McNamee P, Quayyum Z, Royle P, Thomas S. The clinical effectiveness of glucosamine and chondroitin supplements in slowing or arresting progression of osteoarthritis of the knee: a systematic review and economic evaluation. Health Technology Assessment. 2009 Nov 19;13(52):1-48.

[38] Li R, Liang N, Bu F, Hesketh T. The effectiveness of self-management of hypertension in adults using mobile health: systematic review and meta-analysis. JMIR mHealth and uHealth. 2020 Mar 27;8(3):e17776.

[39] Davis Z, Khansa L. Evaluating the epic electronic medical record system: A dichotomy in perspectives and solution recommendations. Health Policy and Technology. 2016 Mar 1;5(1):65-73.