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The Prescription for Value and Efficiency: A Systematic Review of Artificial Intelligence in Optimizing Pharmacy Business and Drug Prices

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Abstract

Background: Healthcare is facing unprecedented stress due to the threat of rising costs, drug shortages, and inefficiency in operations. Pharmacy operations, starting from the manufacturing plant to the patient's bedside, and the complex nexus of drug prices are important areas crying out for disruption. Artificial intelligence (AI), specifically machine learning (ML), natural language processing (NLP), and robotic process automation (RPA), is being viewed increasingly as a game-changing force that can help counter these problems.

Aim: The aim of this systematic review is to integrate current literature and evidence on the application of AI for streamlining pharma operations and justifying drug cost.

Methods: We systematically searched peer-reviewed articles, reports, and clinical trials published between 2010 and 2025.

Results: The findings reflect that AI-based solutions are being used effectively across the value chain of pharma. In operations, AI systems streamline inventory management, automate dispensing, improve clinical decision support, and personalize medication adherence programs. In drug pricing, AI algorithms are transforming market access approaches, optimizing payer reimbursement contracts, and informing value-based pricing models using advanced analysis of real-world evidence (RWE). Although the potential is great, numerous challenges remain, including data privacy concerns, algorithmic bias, the "black box" issue, and regulatory challenges.

Conclusion: The review opines that AI is not only an incremental but also a paradigm change towards improved, safer, and value-based pharmacy practice. Strategic investment, cross-disciplinary convergence, and robust regulatory frameworks are essential to unlock the full potential of AI in creating an enduring and patient-centric pharmaceutical system.

Keywords: Artificial Intelligence, Machine Learning, Pharmacy Operations, Drug Pricing, Inventory Management, Clinical Decision Support, Pharmacoeconomics, Real-World Evidence, Value-Based Care, Automation.

1. Introduction

The pharmacy sector is a critical hub within the healthcare system, facilitating secure, effective, and efficient dispensing of medicinal products to consumers. Notwithstanding this, the pharmacy sector is also riddled with intricacies. The provision of pharmacy services, in terms of community pharmacies, hospitals, and the pharmaceutical supply chain, is faced with challenges between drug errors and stockouts or wastage of inventory, human resources shortages, and rising operational costs (1). Alongside these advances comes the area of drug pricing, which is a hot topic of focus. Skyrocketing drug prices, opaque price methodology, and lack of ability to demonstrate value for money weigh down healthcare budgets and limit patient access to innovative treatments (2).

Artificial intelligence (AI) has emerged as a beacon of hope in this challenging scenario. Artificial intelligence, being the capacity of a machine to mimic intelligent human behavior, encompasses a collection of technologies like machine learning (ML), deep learning, natural language processing (NLP), and robotic process automation (RPA) (3). These technologies are suited best to discover patterns, predict, and execute complex tasks from large and

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scattered datasets—proficiencies specifically designed for the data-driven and process-enabled nature of pharmacy.

Pharmacy's use of AI is not for the future but is an ongoing evolution. Early applications were rule-based clinical decision support, but the current trend for AI is to use ML to move beyond static rules to dynamic, predictive, and personalized knowledge (4). This review will provide an integrative and systematic analysis of the current status of AI use in two related domains: pharmacy operations and drug prices. This review, through the synthesis of evidence from a broad body of literature, will provide a hard-eyed assessment of how AI is revolutionizing the economics and operations of pharmacy to a more sustainable and efficient healthcare system.

Methodology

It was conducted as a systematic review of the literature to ensure a complete and unbiased integration of the existing knowledge.

Search Strategy

A controlled electronic database search of articles from January 2010 to May 2025 was undertaken. The databases searched were PubMed/MEDLINE, Scopus, Web of Science, and EMBASE. Google Scholar was also used for grey literature and to identify highly cited seminal papers. The search was combined by keyword and by Medical Subject Headings (MeSH) terms for the important concepts:

- ("Artificial Intelligence" OR "Machine Learning" OR "Deep Learning" OR "Natural Language Processing" OR "Robotic Process Automation")
- AND ("Pharmacy" OR "Pharmacist" OR "Pharmaceutical Services" OR "Medication Dispensing" OR "Pharmacy Administration" OR "Inventory Management")
- AND ("Drug Costs" OR "Drug Pricing" OR "Pharmaceutical Pricing" OR "Pharmacoeconomics" OR "Market Access" OR "Reimbursement")

Inclusion and Exclusion Criteria

Studies meeting the following criteria were included: (i) were written in English; (ii) described a main application of AI/ML/NLP/RPA; (iii) were directly about pharmacy operations (e.g., dispensing, stock, clinical services) or drug pricing/market access; and (iv) were a peer-reviewed article, conference paper, dissertation, or authoritative industry white paper. Studies were not included if they: (i) were theoretical only and did not include application data; (ii) were drug discovery only with no relevance to operations or pricing; or (iii) were editorials or opinion pieces with no original data or systematic review.

Study Selection and Data Extraction

The initial search yielded over 1,200 records. After removal of duplicates, titles and abstracts were screened against the inclusion criteria. The full text of potentially relevant articles was reviewed. A standardized data extraction form was used to extract information on study authors, publication year, AI technology utilized, narrow application domain, study design, key findings, and reported outcome.

AI in Optimizing Pharmacy Operations

Pharmacy operations constitute a subtle interplay of logistics, clinical expertise, and patient interaction with numerous opportunities for improvement with the use of artificial intelligence. AI is being introduced across the board to significantly improve efficiency, safety, and clinical outcomes and transform traditional pharmacy practice into a predictive and personalized modality.

Inventory Management and Supply Chain Logistics

Poor inventory management is a continuing issue, which leads to huge financial losses from drug wastage and clinical risks due to stockouts. Traditional models, averages, are not ideally equipped to handle the demand variability. AI, particularly machine learning (ML), is revolutionizing this space. ML algorithms can analyze a multitude of variables—including historical dispensing data, seasonal disease patterns, local prescribing trends, and even external factors like weather data—to predict medication demand with high accuracy at the individual Stock Keeping Unit (SKU) level (5). Sophisticated time-series forecasting algorithms like ARIMA and LSTM networks support just-in-time inventory management, with research indicating that there are possible reductions in carrying costs and expiry rates up to 30% (6, 7). In addition to demand forecasting, AI actively prevents supply chain disruptions. Natural language processing (NLP) software may scan FDA databases, drug manufacturer press releases, and global news feeds to notify pharmacies of upcoming shortages of drugs so that backup suppliers or therapy alternatives can be ordered in advance (8). Robotic Process Automation (RPA) robots can also automate the tedium of purchase order generation and invoice processing. When integrated with ML-based demand forecasting, these systems can generate a virtually self-sufficient process for procurement, freeing pharmacy personnel for greater clinical activity (9).

Error Reduction and Dispensing Automation

Dispensing errors remain a persistent patient safety concern, and AI is being used to enhance human checking and construct a more secure, multi-layered verification process. While robot dispensing systems are implemented, integration with computer vision based on artificial intelligence is one huge leap forward. Vision systems can verify the correctness of a chosen pill against a database of millions of images and reduce the chance of wrong drug or wrong strength mistakes significantly, with accuracy levels reported in excess of 99.99%, far exceeding human ability for repeat vision jobs (10, 11). This is augmented by NLP algorithms that are streamlining the process of entering prescriptions. They can read and understand electronically or handwritten prescriptions and cross-check them with the patient's electronic health record (EHR) to check for allergies, drug-drug interactions, and appropriate dosing. This is an initial quality check of utmost significance; one study indicated that an NLP system was able to detect potential errors in 15% of prescriptions already cleared by the technician, an important protection prior to final checking by the pharmacist (12, 13).

Clinical Decision Support and Medication Therapy Management (MTM)

With the pharmacist's future role more and more clinical in nature, Clinical Decision Support (CDS) systems fueled by AI are becoming invaluable partners. They are evolving from rule-based, static databases to dynamic, predictive ones. For instance, ML models can now predict the likelihood and severity of a possible ADE for that patient based on their own clinical profile, genetics (pharmacogenomics), and associated medications (14). This provides for risk stratification, so the most important alerts are attended to by clinicians while limiting the widespread issue of "alert fatigue" by a significant amount (15). In personalized medicine, ML models are extremely useful in the case of medications with a narrow therapeutic index, like warfarin and vancomycin. Through the inclusion of patient-specific factors like age, weight, renal function, and genetic markers, these models can recommend optimized dosing regimens with more accuracy than standard protocols. In a randomized controlled vancomycin trial, for example, it was discovered that increased time within the target range occurred when ML algorithm-directed dosing was utilized as opposed to standard dosing (16, 17). AI also expands Medication Therapy Management (MTM) and adherence support capabilities. Predictive models can analyze claims data, EHRs, and social determinants of health to identify patients most likely to be helped by MTM services and high-risk patients for nonadherence, enabling targeted intervention such as automated recalls or follow-up phone calls (18, 19). Furthermore, NLP-powered chatbots are able to offer pre-medication adherence counseling and answer routine patient questions, thus broadening the boundaries of clinical services and allowing pharmacists to handle more complex cases (20).

Staffing and Workflow Optimization

The all-too-often fragmented nature of pharmacy workflow is another area where AI is making a profound impact. Through tracking historical trends of prescription receipt times, types of prescriptions, and personnel numbers, ML models are able to predict peak workload hours and recommend optimum scheduling of pharmacists and technicians. Predictive workflow management leads to reduced patient wait times and improved staff usage (21). Robotic Process Automation (RPA) is also being used to manage administrative workloads. Streamlined by RPA are routine tasks such as prior authorization initiation, billing, and patient communication (e.g., notification of patients that their prescriptions are ready). This reduces administrative drag, reduces the possibility of human error within these processes, and allows pharmacy staff to redirect their time towards more valuable, patient-facing clinical activities (22). Table 1 and Figure 1 summarize the AI applications in pharmacy operations.

Table 1: Summary of AI Applications in Pharmacy Operations

Application Area	AI Technology	Key Function	Documented Outcomes	Key Challenges
Inventory Management	ML (Time-series forecasting, LSTM), NLP	Demand forecasting, shortage prediction, and automated procurement	Reduced drug wastage (up to 30%), reduced stockouts, lower carrying costs (6, 7, 8)	Data quality and integration, model accuracy with low-demand items, and cost of implementation
Dispensing & Safety	Computer Vision, Robotics, NLP	Automated verification, error checking in prescriptions, robotic picking	>99.99% accuracy in pill identification, reduction in dispensing errors (10, 11, 13)	High capital investment, integration with existing systems, handling of novel drug formulations
Clinical Decision Support	ML, NLP, Deep Learning	Predictive ADE alerts, personalized dosing, drug-allergy checking	Reduced alert fatigue, improved time in therapeutic range for narrow-therapeutic-index drugs (15, 16, 17)	"Black box" problem, clinical validation, integration into clinician workflow, and liability concerns
MTM & Adherence	ML (Predictive Analytics), NLP Chatbots	Identify high-risk patients, predict non-adherence, and automate counselling	Improved patient outcomes, more efficient targeting of clinical resources, and scaled patient education (18, 19, 20)	Patient data privacy, patient acceptance of chatbots, and ensuring message accuracy

Workflow Optimization	ML (Process Mining), RPA	Staff scheduling, automation of administrative tasks	Reduced patient wait times, lower administrative burden, improved staff satisfaction (21, 22)	Resistance to change, process re-engineering requirements, and upfront setup cost for RPA

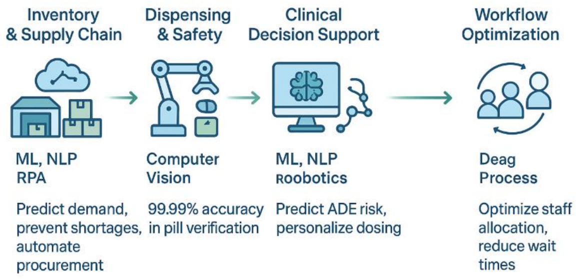

Figure 1. AI-Driven Optimization in Pharmacy Operations

AI in Optimizing Drug Pricing and Market Access

The pricing of medicines is among the most dynamic and volatile aspects of modern healthcare. Artificial intelligence is increasingly at the center of efforts to introduce more objectivity and evidence to this environment, facilitating the move toward more value-based and defensible pricing and market access strategies.

Market Analysis and Price Forecasting

The determination of a launch price for a new drug is a risky business for pharmaceutical companies, which must balance recovering vast R&D costs against gaining market access and demonstrating value. AI significantly enhances the process with advanced analytics. Natural language processing (NLP) is employed to conduct comprehensive competitive landscape assessments by reading thousands of documents, including clinical trial publications, competitor press releases, patent filings, and health technology assessment (HTA) reports (23). This provides a sophisticated perspective on the standard of care, competitor pricing strategies, and how the product can carve out a niche in the market. In addition, machine learning (ML) algorithms can estimate a probable launch price based on attributes of past-drug launches, including clinical efficacy measures (e.g., overall survival gain), mechanism of action, disease incidence, and number of available competitors (24). Such data-driven algorithms allow companies to compare their price expectations to actual precedents from real-world data instead of relying on intuition-based pricing.

Value-Based Pricing and Outcomes Prediction

Healthcare's perpetual shift from volume-based to value-based reimbursement demands robust proof of a medication's real-world effectiveness, a field in which AI is vital. ML algorithms can scan enormous data repositories of real-world evidence (RWE) from electronic health records (EHRs), claims databases, and patient registries to perform comparative effectiveness and cost-effectiveness studies against alternative incumbent options (25). The analysis can be applied directly to value-based pricing discussions with payers. For instance, an AI model can identify patient subpopulations that get the most value out of an expensive oncology therapy and therefore a higher price for that subgroup or establish the basis for an outcomes-based contract (26). Also, because there are limited follow-up periods in standard clinical trials, AI models can predict the long-term economic impact of a medication—i.e., reduced hospitalizations or slowing of disease progression—by extrapolating from short-term RWE, thereby demonstrating a complete and more compelling picture of its worth over time (27).

Payer Strategy and Reimbursement Optimization

Ensuring favorable reimbursement from insurers and payers is critical to commercial viability, and AI models are increasingly being employed to simplify this complex negotiating process. ML classifiers may be trained to estimate the likelihood of a favorable reimbursement outcome from specific payers. They analyze the drug's profile, the composition of the evidence package submitted, and the payer's historical decision patterns, allowing manufacturers to anticipate beforehand how they can modify their submission dossiers and expect forthcoming objections (28). AI is also crucial to the design and use of outcome-based contracts (risk-sharing arrangements), which condition payment for medicines on predefined patient outcomes. It helps to establish appropriate outcome measures, the optimal target patient population, and the automation of monitoring said outcomes from RWE sources, and therefore makes such complicated contracts more administratively feasible for manufacturers and payers alike (29).

Drug Repurposing and Lifecycle Management

In addition to pricing new chemical entities, AI holds profound ramifications for maximizing returns on available assets using drug repurposing and sophisticated lifecycle management. ML techniques can scan massive biological databases—genomic and proteomic—to uncover new drug-disease associations, new therapeutic uses (30). An off-patent drug may reach the market within a few years at a fraction of the cost of a novel drug, with an alternative pricing strategy that can be extremely profitable but greatly enhance patient access (31). From a lifecycle management standpoint, AI may review sales data, patent expiration dates, and competitor actions to recommend best practice strategies for extending the commercial lifecycle of a drug. These include recommending new formulations be created, fixed-dose combinations be created, or new geographic territories be launched, each having direct and strategic considerations for pricing strategies (32). Table 2 and Figure 2 summarize the AI applications in drug pricing and market access.

Table 2. Summary of AI Applications in Drug Pricing and Market Access

Application Area	AI Technology	Key Function	Documented Outcomes / Potential Impact	Key Challenges
Market Analysis & Forecasting	NLP, ML (Regression, Random Forests)	Competitive intelligence, launch price prediction	More informed pricing strategies, better benchmarking against competitor value propositions (23, 24)	Data accessibility (confidential pricing), dynamic nature of markets, regulatory uncertainty
Value-Based Pricing	ML (Causal Inference, Survival Analysis)	RWE analysis, comparative effectiveness, prediction of long-term outcomes	Supports evidence-based price justification, enables outcomes-based contracts, demonstrates value to payers (25, 26, 27)	RWE data quality and bias, establishing causality from observational data, payer acceptance of RWE
Payer Strategy & Reimbursement	ML (Classification Models), NLP	Predicting payer decisions, optimizing contract design	Higher reimbursement success rates, more efficient and scalable outcomes-based contracts (28, 29)	Complexity of payer policies, data sharing agreements for contract monitoring, legal and regulatory frameworks
Drug Repurposing & Lifecycle Mgmt.	ML (Network Analysis, Deep Learning)	Identifying new indications, optimizing patent strategies		

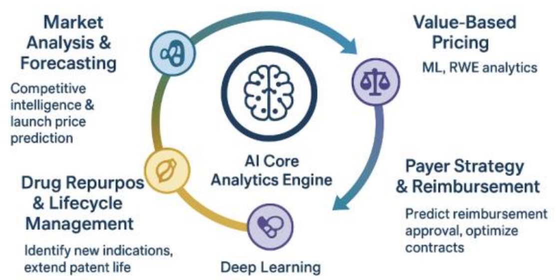

Figure 2. AI Applications in Drug Pricing and Market Access

Challenges, Limitations, and Ethical Considerations

Though enormous, its application in pharmacy practice and medicine pricing is faced with insurmountable challenges that must be addressed before it can be employed safely, efficiently, and equitably. The challenges cross data integrity, algorithmic trustworthiness, and multilateral regulatory and ethical environments.

Data-Related Challenges

The performance of any artificial intelligence (AI) model is necessarily bound to the quality of the data with which it is trained, presenting a fundamental challenge. Incomplete data, incorrect coding, and poor standardization across various electronic health record (EHR) and pharmacy management systems can lead to the development of skewed and inaccurate models (33). This interoperability problem hinders assembling large, robust datasets for training generalizable AI. Furthermore, using sensitive patient health data creates severe security and privacy concerns under laws like HIPAA in the U.S. and GDPR in Europe. Although de-identification techniques are employed, they will have to be extremely resilient, and the building of secure, compliant data environments is completely essential to ensure patient confidentiality and trust (34).

Technical and Algorithmic Challenges

Along with data, several technical limitations are obstacles to the deployment of reliable AI. Above all others is algorithmic bias and fairness. If the training data set is not representative of the greater population—for instance, by underrepresenting specific ethnic groups, age cohorts, or income levels—the AI system can rebuild or even intensify current health inequities (35). A worst-case scenario would be an algorithm learned on a single demographic that could generate risky dosings in another. To this is added the "black box" problem, where the decision-making processes of most advanced machine learning models, particularly deep learning models, are opaque and difficult to comprehend. Lack of explanation of such decision-making processes presents a critical roadblock to trust and adoption by clinicians who have clinical responsibility for patient outcomes and by regulators who require transparency (36). Finally, verifications and generalizability of AI models remain an ongoing challenge. A model should be properly tested on external datasets to ensure that it performs well outside its training environment. A model learned for one health system may fail to generalize to another due to differences in patient populations, local prescribing patterns, or clinical processes (37).

Regulatory and Ethical Challenges

The AI revolution has caught up with the development of associated regulatory and ethical infrastructure. Regulators like the U.S. Food and Drug Administration (FDA) are further refining their process for the evaluation and clearance of AI-based software as a medical device (SaMD). One particular challenge comes with continuous learning algorithms, which adapt and change their conduct after the initial regulatory go-ahead, becoming a moving target to control (38). This innovation has immediate implications for questions of liability and accountability. When patient harm results from a malfunction by an AI system, e.g., a dosing error suggestion, it is challenging to assign liability. Liability could fall upon the software creator, the hospital that implemented the system, or the pharmacist who used or overrode the warning, calling for exact legal and professional criteria (39). Ethically, it is a concern regarding the impact of automation on pharmacy professionals in terms of de-skilling or job loss. Ethically, the principle must be to make AI a tool that aids human knowledge rather than replacing it, so that pharmacists will be freed from mundane tasks and be able to thrive at more intellectual, patient-centered care and ultimately enhance the profession (40).

Future Directions and Conclusion

Synthesis of Findings

This review has demonstrated the ways in which artificial intelligence is transforming the pharmacy setting at its very foundations. In operations, AI is building levels of efficiency, safety, and personalization unprecedented in history, turning pharmacies into more than mere product-dispensing establishments but data-driven healthcare establishments. In the complex realm of drug pricing, AI is making a critical transition away from secretive, cost-driven price models to more transparent, evidence-driven, and value-driven methods of pricing. With the application of real-world evidence (RWE), AI is facilitating the establishment of a more direct and justifiable relationship between a drug's price and patients' health benefits.

Future Directions

The future trajectory of AI in pharmacy is in some promising strides towards combating restrictions today. Federated learning allows for the training of AI models across different decentralized data sources, for example, different hospital EHRs, without the sharing or aggregation of raw patient data. This approach can overcome major data privacy challenges while building more robust, generalizable models through learning from more extensive and diverse datasets (41). To get around the "black box" problem, there is a major research initiative in Explainable AI (XAI), with attempts to develop methods that make AI decisions comprehensible and transparent to clinicians as a vital step towards trust establishment and facilitating widespread clinical adoption (42). In addition, the intersection of AI with other cutting-edge technologies will reveal new potential; this involves integration with the Internet of Things (IoT) to have smart inventory management, blockchain to provide secure and transparent supply chains, and augmented reality to have better training and dispensing verification (43). Finally, the universal application of pharmacogenomic data in AI-enabled clinical decision support will herald an era of true personalized prescribing where drug and dose selection is tailored to an individual's genetic makeup from inception (44).

Conclusion

In conclusion, artificial intelligence is a disruptor for the entire pharmacy sector. Its applications in rationalizing operations and rationalizing the cost of medicines are not incremental benefits but can set off a systemic change towards a leaner, safer, equitable, and value-driven model of pharma care. The problems, from bias and quality of data in the algorithms to regulatory and ethics concerns, exist, to be sure, but are not insurmountable. Leaping off the full potential of this transformation will require a sustained, collective effort from all stakeholders: pharmacists, data scientists, healthcare administrators, pharmaceutical executives, regulators, and patients. Strategic investment, continuing education, developing robust ethical and regulatory foundations, and an unwavering commitment to a human-centered design ethic are mandatory. The pharmacy future is intelligent, data-informed, and, with wise stewardship, can be profoundly human.

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