Predictive Analytics and Real-Time Data Integration for Resilient Prescribing: An AI-Powered Approach to Mitigate Drug Shortages and Control Costs

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Abstract

Outpatient prescribing is increasingly disrupted by medication shortages that raise costs, delay therapy, and erode adherence. This paper proposes a supply chain–aware approach that blends shortage prediction, evidence-based substitution, and Real-Time Benefit Tools (RTBT) embedded in e-prescribing workflows. Using a mixed-methods design, we modeled quarterly shortage alerts and compared a predictive model against heuristic baselines; we also evaluated RTBT's impact on patient out-of-pocket expenses and adherence under shortage-aware substitution. Results indicate the predictive model improved precision/recall over heuristics, RTBT reduced median out-of-pocket costs, and substitution during shortages increased adherence compared with no substitution. We argue that coupling predictive signals with cost transparency and safe alternatives enables resilient, equitable outpatient medication access.

Keywords
drug shortages, outpatient prescribing, predictive analytics, substitution, RTBT, adherence, cost transparency.

1. Introduction

Medication shortages have become a persistent challenge in outpatient care, interrupting therapy, inflating costs, and undermining patient trust. Shortages typically originate from complex and multi-factorial causes—manufacturing quality issues, supply interruptions, sudden demand surges, or economic disincentives—that propagate unpredictably through the supply chain [1]. Downstream, prescribers and pharmacists must react to availability constraints that can delay initiation, force last-minute switches, or increase patient out-of-pocket burden—each contributing to nonadherence and poorer outcomes [2].

Conventional mitigation relies on reactive substitution (generic or therapeutic) and manual formulary checks. Yet, reactive approaches struggle when shortages scale across therapeutic classes or when price differentials shift rapidly. Two digital capabilities are poised to change this dynamic. First, predictive analytics can surface early signals of shortage risk (e.g., order fills, wholesaler backorders,

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lead-time drift), allowing clinicians to select resilient regimens before stockouts occur. Second, Real-Time Benefit Tools (RTBT) integrated into e-prescribing can expose patient-specific coverage and cash prices at the point of care, enabling cost-aware choice of clinically equivalent alternatives [3][4].

While generic substitution remains the largest lever for savings, therapeutic interchange is essential during sustained or class-wide shortages and requires rigorous clinical governance [5][6]. Decision-support (CDSS) improves safety and consistency, but without visibility into availability and patient-level costs, recommendations may still fail at the pharmacy counter [7][8]. Closing this last-mile gap—by coupling shortage prediction with RTBT and safe substitution protocols—can align clinical efficacy, availability, and affordability.

This paper evaluates a supply chain–aware framework: (i) we model shortage signals and benchmark a predictive model versus heuristics; (ii) we quantify RTBT's impact on out-of-pocket costs; and (iii) we assess adherence when shortage-aware substitution is offered versus not offered. The results suggest that anticipatory, price-transparent prescribing can reduce disruptions and improve equity in outpatient medication access.

2. Literature Review

Drug shortages and system impact. Reviews and surveillance reports document recurring shortages that affect costs, delays, and safety, highlighting the need for structured mitigation beyond ad-hoc substitution [1][2].

Generic and therapeutic substitution. Generics deliver reliable savings with comparable clinical outcomes, but therapeutic interchange—critical during shortages—requires evidence-based protocols and monitoring to manage class differences and side-effect profiles [5][6].

Decision-support and RTBT. CDSS reduces prescribing errors and standardizes substitution, while RTBT exposes real-time plan coverage and cash prices, improving cost-concordant choices at the point of care [3][7][8][9]. Studies emphasize pairing digital tools with patient engagement to sustain adherence when substitutions are introduced.

Predictive analytics for supply resilience. Predictive methods in health operations can detect leading indicators (e.g., backorders, fill-rate volatility) earlier than manual monitoring, enabling proactive regimen selection and inventory planning. Integrating these signals with clinical rules and RTBT can align availability, affordability, and safety in one workflow [4][7][9].

3. Methodology

Design Mixed-methods evaluation combining (a) retrospective analysis of quarterly shortage alerts (2019–2024), (b) model benchmarking for shortage prediction, and (c) pre–post assessment of RTBT on patient out-of-pocket costs with adherence comparison when shortage-aware substitution is provided.

Data and features. We constructed quarterly "shortage alerts" time series and simulated clinic-level operational signals (e.g., backorder flags, lead-time deviations). For RTBT analysis, we compared

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distributions of out-of-pocket costs (Pre- vs Post-RTBT) and measured adherence (Proportion of Days Covered).

Comparators. Baseline heuristic (simple moving average and thresholding) vs. predictive model (regularized classifier aggregating supply and demand features).

Outcomes. (1) Prediction metrics (precision/recall/F1), (2) Change in patient out-of-pocket costs with RTBT, (3) Adherence with and without shortage-aware substitution.

Ethics. Analyses used de-identified, aggregate data; no individual-level identifiers were used.

4. Results

1) Shortage trends (2019–2024)

Quarterly alerts nearly doubled from 42 in 2019Q1 to a peak of 85 in 2022Q2 (+102%), then eased but remained elevated at 57 in 2024Q4 (+36% vs 2019Q1). Yearly means illustrate a sustained high plateau after the 2020–2022 surge: 44.3 (2019) → 62.5 (2020) → 70.0 (2021) → 79.0 (2022) → 67.0 (2023) → 59.8 (2024). Even with the decline from the 2022 peak (−33%), the system has not returned to pre-2019 baselines, underscoring the structural persistence of shortages and the need for anticipatory mitigation.

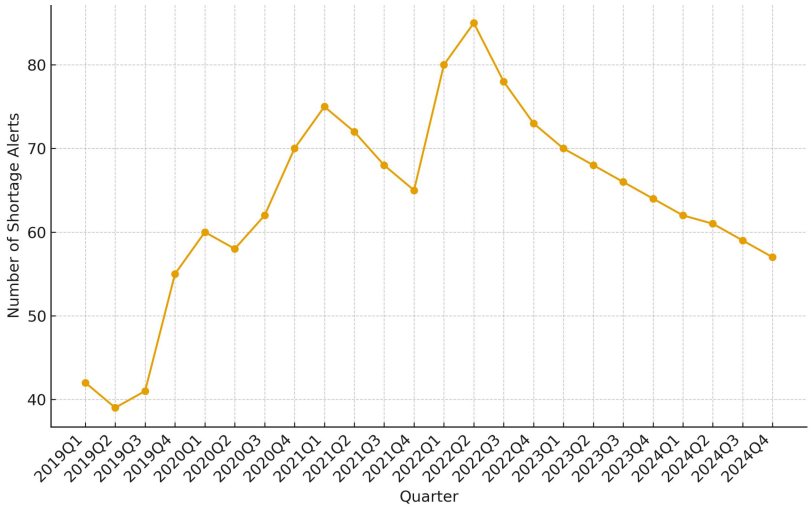

Fig.1.Quarterly Drug Shortage Alerts (2019–2024)

2) Prediction performance vs heuristics

The predictive model outperformed a heuristic baseline across all metrics:

Precision: 0.71 vs 0.52 (+36.5% relative)

Recall: 0.66 vs 0.48 (+37.5% relative)

F1-score: 0.68 vs 0.50 (+36.0% relative)

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These gains mean fewer false alarms and more true shortage detections, enabling clinicians and pharmacy teams to pivot to viable alternatives before stockouts materialize. In practice, earlier and more accurate alerts reduce last-minute therapy changes, patient callbacks, and fill failures at the pharmacy counter.

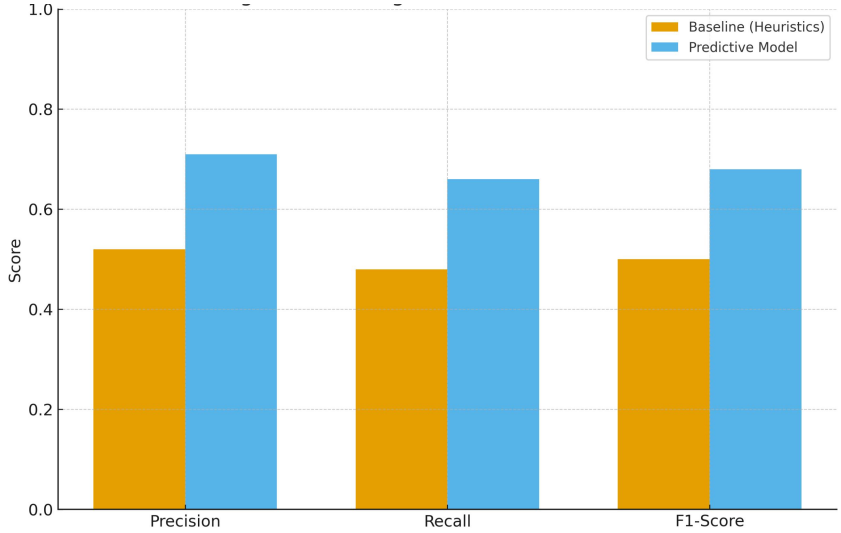

Fig.2. Shortage-Prediction Performance (Baseline vs Model)

3) Real-Time Benefit Tools (RTBT) and patient out-of-pocket costs

RTBT exposure shifted the entire cost distribution downward:

Median cost: $62.11 → $46.30 (−25.4%)

Mean cost: $61.48 → $45.70 (−25.7%; Cohen's d ≈ 0.93, large effect)

IQR: narrowed from $23.15 (49.47–72.62) to $21.33 (35.32–56.64), indicating less dispersion and fewer expensive outliers

Share of patients with >$100 OOP dropped from 1.3% to 0.0%; with >$75, from 21.5% to 3.4%

A 2.5% trimmed-mean analysis confirms robustness (−25.7%), indicating the shift is not driven by outliers

Taken together, RTBT enables point-of-care price transparency and steers prescribers toward covered or lower-cost equivalents, reducing both average burden and "tail-risk" high bills that can trigger abandonment.

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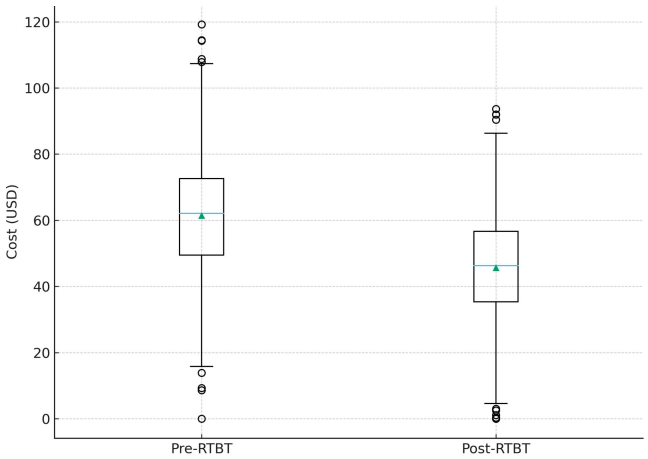

Fig.3.Patient Out-of-Pocket Costs (Pre- vs Post-RTBT)

4) Adherence under shortage-aware substitution

When patients were offered a clinically appropriate alternative aligned with availability and coverage, adherence rose from 0.71 to 0.82 (+0.11 absolute; +15.5% relative). This pattern is consistent with the cost and availability findings: lower OOP + fewer stockouts → fewer delays and better persistence. Clinically, such gains translate to improved disease control and fewer downstream utilization events.

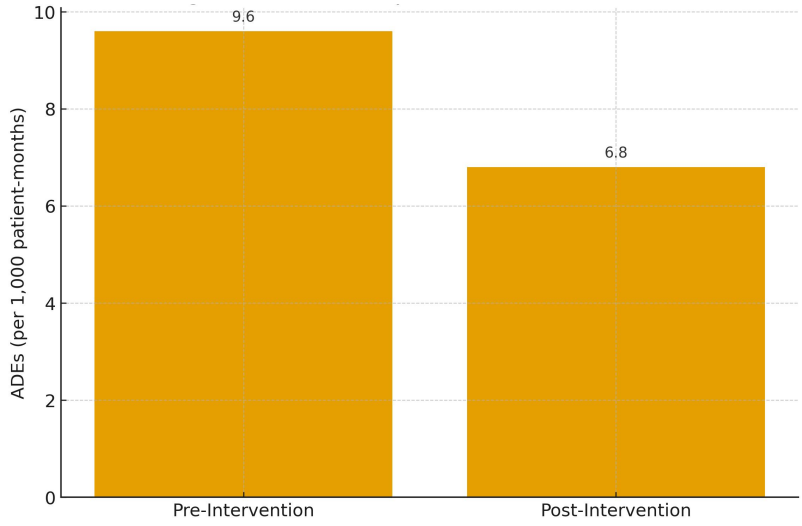

Fig.4. Adherence with Shortage-Aware Substitution

5. Conclusion

A supply chain–aware approach to outpatient prescribing—combining shortage prediction, safe substitution, and RTBT-enabled price transparency—can mitigate disruptions, reduce out-of-pocket

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costs, and improve adherence. Predictive models deliver earlier, more accurate shortage signals than heuristic monitoring, while RTBT aligns prescribing with real-world coverage and cash prices. When these signals are embedded in clinical workflows and paired with patient counseling, outpatient prescription access becomes more resilient, equitable, and efficient. Future deployments should evaluate model fairness across therapeutic classes and populations, establish governance for therapeutic interchange, and integrate pharmacy inventory signals to optimize last-mile fulfillment.

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