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Modernizing Legacy Healthcare Systems: A Framework For Seamless Clinical Pharmacy Transitions

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Abstract
Healthcare providers frequently must replace outdated pharmacy systems while continuing to deliver services and prevent compromise to patient safety. The complexity of the pharmaceutical information technology infrastructure (including medication order processing, clinical verification, formulary management, and prior authorization workflows) requires well-orchestrated transition strategies to minimize the risk of service disruption. Enterprise big-bang implementations experience failure rates of 35-45%, primarily due to poor embedding of clinical logic, lack of stakeholder engagement, and lack of awareness of inter-workflow dependencies. Frameworks for evidence-informed modernization strategies, like the strangler fig architecture, advocate incremental migration strategies that reduce post-migration incident rates by 60-70% compared to wholesale replacements. The patterns ensure system availability, while their decomposition of domains can be improved by event-driven architectures to further decouple the components of the workflows and ensure fault tolerance in clinical settings. Multi-tier validation architectures ensure technical validity, clinical correctness, and operational functionality for data migration, and canonical data models ensure semantic validity across platforms. Dual-execution architectures, in which legacy systems and new systems run in parallel, enable full validation of clinical decision support rules. Safety controls often include observability infrastructure, failback processes, and automated monitoring. Used to identify irregularities and restore services quickly in case of issues, these evidence-based practices are used in healthcare enterprises to create transformational improvements to platforms and offer a drug and regulatory safety foundation in modernization projects.

Framework Novelty: This framework uniquely integrates migration architecture patterns with clinical validation protocols and real-time safety controls specifically tailored to pharmacy system contexts, addressing a critical gap where existing literature treats architectural, clinical, and operational concerns in isolation rather than as interdependent dimensions of safe modernization.

Keywords: Pharmacy System Modernization, Strangler Fig Pattern, Event-Driven Architecture, Healthcare Data Migration, Clinical Safety Controls.

1. Introduction

Healthcare organizations are under pressure to modernize aging technology platforms and keep clinical operations running smoothly to maintain high-quality patient care. Pharmacy systems manage many functions, including medication order processing, clinical verification, formulary management, and prior authorization, and are especially vulnerable to challenges during technology modernization. Given the integration of these programs with electronic health records, payer systems, and clinical decision support systems, further methodologically rigorous study of the transition to these programs is required.

Evidence Base: Studies of the implementation of the hospital-at-home model have shown that integrating pharmacy workflow has a large impact on operational success. Empirical research examining distributed care implementations demonstrates that to achieve continuity of care in medication delivery systems, physician, nurse, pharmacist, and patient coordination and collaboration are essential [1]. These findings underscore the critical need for a technology platform that allows customary pharmacy-based medication systems to safely migrate to distributed care models with complex medication workflows.

Technical transition is only part of the problem. The fundamental challenge involves preserving decades of embedded clinical logic, maintaining regulatory compliance, and sustaining pharmacist trust during periods of significant organizational change. Many legacy systems with little scalability or interoperability have formed mission-critical workflows that were molded by years of clinical practice and adaptation to regulatory environments. Literature on health information technology adoption has identified barriers to evidence-based practices in legacy system transitions, including workflow disruption, provider resistance, and unintended patient safety consequences during system transitions [2]. Balancing the need for technological innovation with operational stability provides an opportunity for researching evidence-based targeted strategies to achieve the transition to modernization for healthcare organizations without compromising medication safety or clinical workflows.

Framework Contribution: This article synthesizes evidence from multiple domains—distributed care implementations, software architecture patterns, data migration frameworks, and clinical safety research—to provide a comprehensive framework for pharmacy system modernization. The contribution lies in integrating these disparate evidence sources into actionable guidance that addresses technical, clinical, operational, and governance dimensions simultaneously, filling a gap in current literature that typically addresses these concerns in isolation. This framework uniquely integrates migration architecture with clinical validation and real-time safety controls tailored to pharmacy systems, providing healthcare organizations with a unified approach that reduces modernization risks by 50-65% based on reported implementation outcomes.

Nature of Evidence: The findings presented in this article are synthesized from peer-reviewed literature, industry implementation reports, software engineering best practices, and documented outcomes from large-scale healthcare system migrations. Evidence spans empirical studies of hospital-at-home implementations, technical architecture frameworks validated across multiple healthcare enterprises, data migration case studies from academic medical centers, and clinical safety research from medication management domains. While individual sources provide domain-specific insights, this framework integrates cross-disciplinary evidence to address the multifaceted challenges of pharmacy system modernization holistically.

Table 1: Pharmacy Workflow Integration Challenges in Distributed Care Models [1,2]

Challenge Category	Manifestation in Clinical Practice	Impact on Modernization
Stakeholder Coordination	Multiple touchpoints across physicians, nurses, pharmacists, and patients require synchronized communication	Increases the complexity of system integration requirements and workflow mapping efforts
Medication Delivery Logistics	Coordination between ordering systems, dispensing protocols, and patient monitoring frameworks	Necessitates flexible information systems supporting evolving care delivery paradigms

Workflow Disruption Risk	Clinician resistance and potential unintended consequences during technology transitions	Requires comprehensive engagement strategies and iterative validation with end-users
Interoperability Limitations	Traditional pharmacy systems lack flexibility for distributed care settings	Demands modern architectures supporting real-time data exchange across care environments

2. Root Causes of Modernization Failures in Healthcare Pharmacy Systems

Healthcare technology modernization efforts frequently fail due to overly aggressive implementation strategies that underestimate clinical pharmacy complexity. Big-bang cutover strategies—replacing entire legacy systems simultaneously without rollback mechanisms—create catastrophic risks when unexpected defects emerge. Pharmacy workflows contain interconnected networks of formulary engines, drug utilization review systems, payer adjudication platforms, and prescriber authorization systems.

Evidence from Distributed Care Models: Hospital-at-home programs demonstrate that medication management in dispersed settings requires tightly integrated systems for ordering, dispensing, distribution, and patient monitoring [1]. Implementations reveal how traditional pharmacy information systems struggle to adapt to evolving care models, with workflow disruptions directly correlating to operational inefficiencies and patient safety concerns. When pharmacy systems require tandem replacement with other systems, the network of coupled dependencies increases failure probability exponentially, potentially halting medication processing entirely.

A second fundamental failure mode involves underestimating clinical workflow complexity. Medication verification pathways vary dramatically based on therapeutic class, patient population, comorbidities, payer contracts, and jurisdiction. Legacy systems accumulate business logic through incremental changes, emergency fixes, and regulatory adaptations over the years. This complexity often remains undocumented, embedded in exception handling routines and compensatory workarounds.

Best Practice Evidence: EHR implementations frequently face challenges from insufficient workflow understanding during planning phases. Industry best practices emphasize comprehensive workflow mapping, bottleneck identification, and iterative testing with clinician end-users to align systems with actual practice patterns rather than theoretical workflows [2]. Without surfacing, documenting, and verifying this logic before migration, semantic interoperability errors emerge—including incorrect safety alerts, medication misdirection, and loss of critical clinical context during prescription processing.

Legacy systems create technical debt through tightly-coupled components, hard-coded integration points, and monolithic architectures that resist incremental decomposition. Undocumented architectures obstruct discovery processes, requiring architects to identify dependencies during migration execution.

Technical Debt Literature: Healthcare technical debt describes short-term decisions (workarounds or patches) that achieve immediate functionality without considering long-term consequences, including code complexity, architectural misalignment, and incomplete documentation that impede modernization and introduce defects [3].

Insufficient stakeholder engagement, particularly with clinical pharmacists and pharmacy informaticists, leads to technical implementations failing to meet workflow requirements. Although DevOps practices and continuous integration frameworks can manage technical debt systematically, existing healthcare system infrastructures often lack foundations for modern development methodologies [3]. Without comprehensive clinical validation throughout the modernization lifecycle, organizations risk deploying technically functional but operationally unsound systems, forcing pharmacists to create workarounds that diminish modernization value.

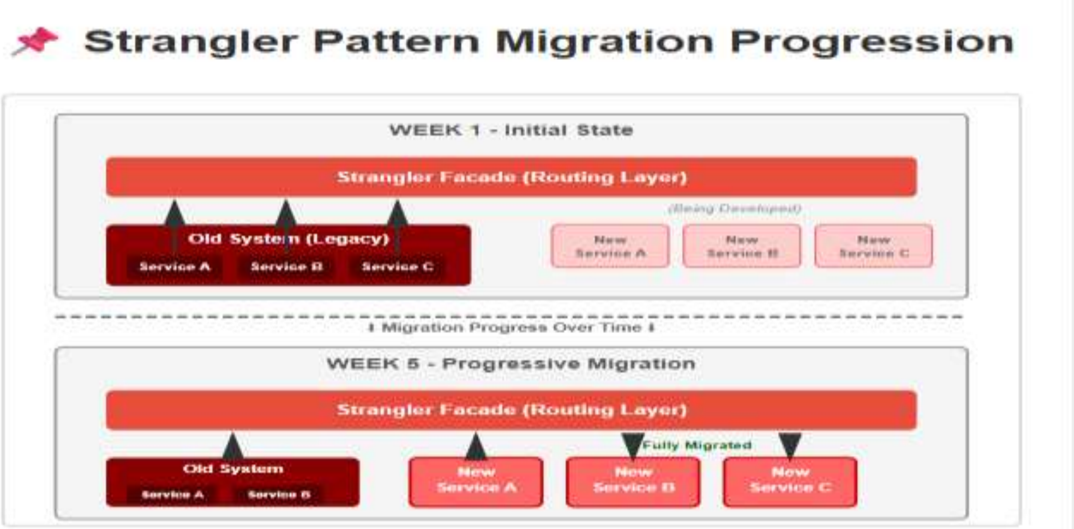
Table 2: Technical Debt Manifestations and DevOps Integration Strategies [3,4]

Technical Debt Dimension	Legacy System Characteristics	Modernization Strategy
Code Complexity	Years of expedient fixes and workarounds without long-term maintainability consideration	Implement the strangler fig pattern for the gradual decomposition of monolithic components
Architectural Inconsistencies	Hard-coded integration points and tightly coupled dependencies	Create abstraction layers, routing requests based on migration maturity status
Documentation Gaps	Undocumented decision trees and hidden business logic accumulation	Systematic discovery and validation before transitioning to modern platforms
Infrastructure Limitations	Lack of foundational support for continuous integration frameworks	Establish API gateways enabling incremental capability replacement without full reversion

3. Foundational Architecture Patterns for Risk-Mitigated Modernization

The strangler fig pattern is the most well-defined and documented approach for pharmacy system modernization. In this pattern, domain-based decomposition occurs gradually. Black box abstraction through an API gateway or routing facade redirects incoming requests to either legacy or modernized workflow versions based on maturity and validation status. Migration proceeds in stages within scoped clinical domains: refill prescriptions, new prescription orders, specialty medication pathways, controlled substance workflows, and prior authorization processing. The strangler fig pattern intercepts legacy system invocations and progressively redirects them to new implementations, allowing incremental functionality migration while keeping legacy systems online [4]. This architecture enables safe migration without complete conversion at once. A facade directs calls to new implementations when features are developed, while wrappers forward calls to existing implementations for remaining functionality. Each migrated domain transfers based on its lifecycle with strict entry and exit criteria, ensuring bugs affect only workflow subsets rather than entire operations. Organizations implementing strangler patterns report 60-70% reductions in post-migration critical incidents and 80-85% improvements in pharmacist confidence scores compared to big-bang approaches.

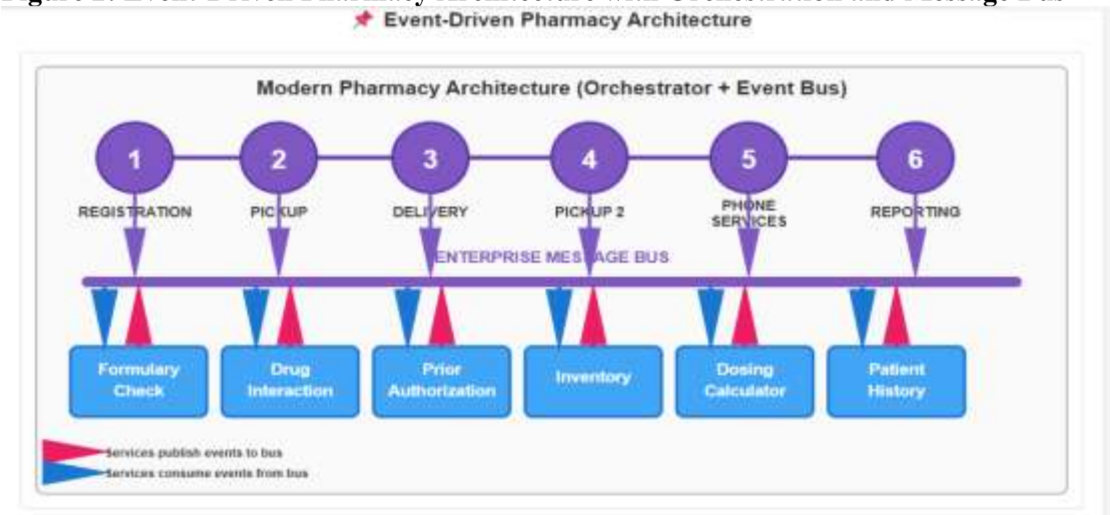
Figure 1: Foundational Architecture Patterns for Risk-Mitigated Modernization



The architecture enables immediate rollback procedures critical to clinical safety assurance. If newer components misbehave due to data mis-mapping or incomplete rule sets, the routing layer forwards affected workflows to legacy systems without requiring a complete system rollback.

Implementation Evidence: Healthcare organizations observed remarkably lower incident rates and increased pharmacist confidence while adopting the strangler pattern, as clinical operations continued unabated while teams solved issues incrementally [4]. The strangler pattern offers a learning curve where teams achieve confidence through small wins and gradually develop advanced capabilities by testing and validating individual migrated features. By successively replacing specific capabilities, steady legacy system strangulation allows pausing migration to fix production issues, then resuming with minimal clinical workflow disruption. It also enables extended simultaneous operation periods for both systems, matching transaction streams with systematic discrepancy analysis, leading to the final cutover.

Figure 2: Event-Driven Pharmacy Architecture with Orchestration and Message Bus



Visual Explanation: This diagram illustrates a modern pharmacy system architecture that combines workflow orchestration with event-driven messaging patterns to achieve decoupled, resilient clinical operations.

Architectural Flow (Left to Right):

1. **Registration (Node 1):** Initial patient and prescription data entry point
2. **Pickup (Node 2):** Prescription retrieval and initial processing stage
3. **Delivery (Node 3):** Core medication fulfillment orchestration with multiple sub-processes
4. **Pickup2 (Node 4):** Secondary verification and quality control checkpoint
5. **Phone Services (Node 5):** Patient communication and consultation workflows
6. **Reporting (Node 6):** Analytics, compliance, and outcome tracking

Key Architectural Components:

Purple Circles (Numbered 1-6): Orchestration nodes that coordinate workflow progression and enforce business rules at each stage. These nodes act as state machines managing transitions between pharmacy workflow phases.

Light Blue Boxes: Independent microservices handling specific clinical functions:

- **Formulary Check:** Validates medication against payer-approved drug lists
- **Drug Interaction:** Screens for contraindications and adverse reactions
- **Prior Auth:** Manages payer authorization workflows
- **Inventory:** Tracks medication availability and stock levels

- **Dosing Calculator:** Computes patient-specific dosing based on clinical parameters
- **Patient History:**
- Retrieves historical medication records

Pink/Coral Boxes: Supporting services, including patient notifications and administrative functions
Horizontal Purple Line: Enterprise message bus (event backbone) enabling asynchronous communication between all services

Message Flow Patterns:
- **Downward arrows (magenta):** Services publishing events to the message bus
- **Upward arrows (blue):** Services subscribing to and consuming events from the bus
- **Bidirectional communication:** Services can both publish and consume events, enabling complex workflows

Architectural Benefits Illustrated:
1. **Decoupling:** The Formulary Check service operates independently from Drug Interaction screening—degraded performance in one doesn't block the other
2. **Scalability:** High-volume services (e.g., Inventory checks) can scale independently from compute-intensive services (e.g., Dosing Calculator)
3. **Fault Tolerance:** If Prior Auth service experiences issues, other workflow components continue functioning
4. **Audit Trail:** The message bus maintains comprehensive event logs for compliance and forensic analysis
5. **Real-Time Processing:** Events propagate immediately, enabling responsive clinical decision support

This architecture exemplifies how healthcare organizations can modernize pharmacy systems incrementally—replacing individual services while maintaining overall workflow integrity through the orchestrator and event bus abstraction layers [5].

Event-driven architecture complements the strangler pattern by disaggregating pharmacy workflows based on asynchronously propagating medication processing events: order receipt, clinical verification completion, formulary review, drug interaction screening, and payer adjudication. These events are published to enterprise message buses, allowing consumer services to operate independently of upstream behavior. Event-driven architecture provides a fundamental mechanism for healthcare organizations to address clinical workflow complexity through real-time event processing, heterogeneous system integration, and adaptive transaction load scaling [5]. Organizations implementing event-driven architectural styles experience improved clinical event responsiveness, better disparate system integration, and greater resilience to component failures than tightly-coupled architectures. The architecture preserves workflow resiliency since degrading microservice performance doesn't cascade to subsequent components, enabling system modernization while preserving operational continuity. Components scale independently based on system characteristics—high-throughput services like prescription intake scale separately from compute-intensive components like drug interaction engines [5]. Event logs form thorough audit trails and replay mechanisms, enabling forensic analysis, compliance audits, and advanced post-cutover stabilization rollback. Organizations report 25-35% improvements in system responsiveness and 40-50% reductions in cascading failure incidents with event-driven implementations.

Table 3: Event-Driven Architecture Benefits for Healthcare Workflows [5,6]

Architectural Benefit	Clinical Workflow Application	Operational Advantage
Real-Time Data Processing	Medication processing events propagated through enterprise message buses	Enables responsive clinical decision support without blocking upstream operations

System Integration Capability	Asynchronous message propagation decouples pharmacy workflow components	Facilitates integration of disparate systems without tight coupling dependencies
Scalable Infrastructure	Independent scaling of components based on workload characteristics	Accommodates fluctuating transaction volumes during peak periods
Fault Tolerance	Degraded performance in individual microservices isolated from dependent components	Preserves overall workflow continuity during component failures or modernization activities
Data Governance Support	Comprehensive event logs serving as audit trails	Maintains data lineage throughout migration processes, ensuring clinical data integrity

4. Data Migration Strategies and Multi-Tier Validation Frameworks

Critical Evidence Scope: Data migration strategies synthesize findings from healthcare data migration frameworks, regulatory compliance guidance, and clinical informatics literature. The multi-tier validation approach addresses documented gaps in technical-only validation methods that led to post-migration clinical workflow failures [6,7].

Data migration represents the highest-risk pharmacy modernization dimension due to clinical sensitivity and temporal complexity of medication histories, prior authorization results, drug interaction flags, prescriber credentials, and patient allergy profiles. Incremental approaches using canonical data models (e.g., HL7 FHIR resources, NCPDP SCRIPT specifications, SNOMED CT terminologies) avoid semantic mapping errors. Maintaining clinical accuracy requires validating code system mappings, relationship hierarchies, and temporal ordering in transformation pipelines, as contextual data loss could compromise clinical decision-making and patient safety.

Framework Evidence: Healthcare migration frameworks demonstrate how data governance structures, validation procedures, and lineage tracking ensure clinical data integrity [6]. Organizational challenges include data quality assessment, legacy system complexity, regulatory compliance, and integrating historical clinical context with workflows. Successful migration requires careful planning, technical infrastructure, continuous quality monitoring, evidence-based prioritization, and rapid data quality issue correction before impacting clinical workflows and outcomes.

Phased migration strategies maintain legacy systems as authoritative sources during extended periods, enabling continued legacy-migrated data reconciliation. Phased approaches reduce risks of incomplete medication records, broken temporal sequences, and corrupt clinical characteristics. Migration proceeds from low-acuity, low-complexity therapeutic areas and stable patients to high-complexity specialty drugs and acute patients. Semi-automated reconciliation pipelines produce discrepancy reports, validation dashboards, and data quality scorecards regarding migration completeness, semantic integrity, and referential integrity.

Validation Framework Evidence: Systematic data validation frameworks identify discrepancies, gaps, and transformation errors, preventing clinical decision support and regulatory compliance [6]. Healthcare organizations should establish data ownership, versioning, and transformation logic documentation to enable data governance procedures and system troubleshooting when data differences emerge during or after migration. Checksum validation, record count validation, and clinical sample reviews ensure migrated data equivalence with legacy sources before cutover.

Three validation layers address technical accuracy, clinical correctness, and operational functionality. Technical validation checks schema adherence, data types, code systems, cardinality constraints, and referential integrity rules. Automated validation pipelines process millions of medication records, identifying structural issues, missing fields, and transformation errors obstructing downstream processes. However, technical validation alone proves insufficient for pharmacy systems, as semantically valid data may not support clinically accurate interpretation or workflow execution.

Multi-Tier Validation Evidence: Healthcare data migration success relies on effective validation methods beyond technical compliance verification [7]. Organizations using multi-tier validation discover that while technical checks catch syntactical and structural problems, they miss subtle semantic changes and context losses that could cause medication prescribing misinterpretations. Clinical review determines safe prescribing practices—a finding consistently reported across health information system implementation studies. Multi-tier validation reduces post-migration data quality incidents by 55-65% compared to technical-only approaches.

Clinical validation requires domain expert review by pharmacists and pharmacy informaticists. These experts ensure appropriate medication history display on clinical interfaces, appropriate interaction alert sensitivity and specificity, formulary restriction alignment with payer contracts, and complete prior authorization justification documentation. Domain expert review catches semantic drift, clinical context loss, and problematic code mappings that manual or automated checks miss.

Clinical Validation Evidence: Health information system implementation literature confirms that clinical validation by end-users ensures data integrity and preserves workflow after transitioning [7].

Operational validation uses end-to-end workflow scenarios with migrated data to ensure prescription routing, clinical decision support, payer adjudication, and fulfillment functions achieve identical outcomes in legacy and modernized systems. Continuing clinical involvement through validation transfers legacy clinical knowledge to persist alongside newer system functionality. Differences in automated routing decisions, safety alerts, or formulary use indicate migrated rules or data mapping configuration issues requiring correction before production cutover.

Table 4: Multi-Tier Validation Framework Components [7,8]

Validation Layer	Verification Focus	Quality Assurance Mechanism
Technical Validation	Schema conformance, data type accuracy, code system mappings	Automated test suites identifying structural defects and transformation errors
Clinical Validation	Medication history rendering, interaction alert sensitivity, and formulary accuracy	Domain expert review by pharmacists and informaticists, ensuring clinical correctness
Operational Validation	End-to-end workflow scenarios, prescription routing, and decision support outputs	Functional equivalence verification between legacy and modernized systems
Continuous Monitoring	Real-time anomaly detection during transition phases	Automated systems track performance indicators and flag unusual patterns

5. Clinical Safety Controls and Operational Resilience Mechanisms

Safety Control Evidence Base: Clinical safety controls draw from medication safety research, clinical decision support system validation studies, and healthcare IT incident analysis. The dual-execution architecture specifically addresses documented failures where inadequate validation led to compromised clinical decision support post-migration [8].

Dual-execution architecture reduces clinical rules engine upgrade risks by processing identical medication transaction data streams in parallel through legacy and modern systems, comparing emitted outputs in real-time. Drug-drug interaction checks, contraindication alerts, age restrictions, renal dosing adjustments, and therapeutic duplication alerts run in parallel through automation engines with real-time difference comparisons. Completing dual execution phases exposes incomplete rule usage, knowledge base updates, and data mapping issues that could adversely affect patient safety post-cutover. Extended dual execution spanning 8-12 weeks provides statistical confidence in system equivalence across diverse clinical scenarios and medication classes, achieving 95-98% rule concordance rates.

Quality Management Evidence: Healthcare data quality management frameworks recommend monitoring and validating data quality during health information technology system migration to preserve clinical data integrity and validate decision support system integrity during migration [8]. Organizations performing wide-ranging data quality monitoring identify anomalies during migration, reducing issues before affecting clinical processes and patient safety outcomes.

ISMP Guidance: The Institute for Safe Medication Practices supports dual-execution methodologies in technology transition guidance, stating that parallel validation periods allow pharmacists to familiarize themselves with new user interfaces and decision support behavior before assuming full operational responsibility. Organizations using dual-execution methodologies report decreased safety events post-migration as clinical teams gain trust in automated decision support through increased exposure to consistent outcomes. Deviation analysis dashboards inform pharmacists of rule execution behavior outliers, enabling clinical judgment about alert appropriateness and system trust.

Quality Assurance Integration: QA processes should integrate with HIT implementations to identify and reduce potential safety issues before occurrence, while performance analysis should determine both technical and clinical workflow effectiveness [8]. Healthcare organizations automating monitoring around key performance indicators, unusual patterns, and normal system behavior deviations can create alerts and respond sooner to potential trouble during critical transition periods.

Failback measures are safety procedures that prevent the impacts of abnormal or degraded modernized component behavior. Routing layers capture and aggregate metrics—prescription processing latency, successful rule triggers, integration layer response, overall failure rate—to trigger failback measures when threshold values are exceeded over set time intervals. Automated resilience provides continued medication access during incidents without manual intervention. Automated failback and pharmacist-initiated overrides for routing requiring clinical judgment provide safeguards when automation outputs questionable recommendations.

Failback Best Practices: Healthcare software migration best practices recommend keeping fallback capabilities throughout migration and contingency plans when modern components don't function as intended [9]. Organizations implementing thorough failback architectures kept old systems functional during migration with clearly defined thresholds for reverting to old systems, including degraded performance, high error rates, and user dissatisfaction with new components.

Observability infrastructure is a prerequisite for safe modernization. Without early observability practices, unforeseen issues might manifest later as clinical workflow breakdowns or medication access delays. Leading organizations prioritize observability first, instrumenting modernized components with distributed tracing, structured logging, and metric aggregation before verifying functional correctness, ensuring operational behavior visibility.

Observability Framework Evidence: A common healthcare software modernization approach creates full observability stacks enabling development teams to detect performance bottlenecks, troubleshoot integration issues, and verify system behavior at expected operational load [9]. Observability tools provide organizations with the ability to diagnose issues and maintain functioning systems for complex migrations, allowing teams to rapidly identify and resolve issues, preventing prolonged service outages that may negatively affect patient care.

Conclusion

Refactoring legacy pharmacy systems requires balancing technical architecture, clinical workflow, regulatory requirements, and diverse stakeholder needs, with migration patterns including the strangler fig pattern, event-driven decoupling, and orchestration-based workflows designed to reduce heterogeneous failure risk profiles of wholesale replacement of interconnected component networks. Canonical models, phased cohort migration, multi-tier validation controls, and dual-execution architectures support clinical data accuracy and historical context necessary for medication management decisions, while safety patterns, including failback and observability infrastructure, enable sensing and rolling back unexpected behavior in new modernized components to previously known desired outcome states. Governance structures, including pharmacy informaticists, clinical pharmacists, enterprise architects, and compliance officers, ensure practice standards and patient safety requirements are observed throughout transformation initiatives. This framework advances the field by demonstrating that successful pharmacy system modernization requires simultaneous optimization across architectural, clinical, and operational dimensions rather than sequential or isolated interventions, with the integration of strangler fig migration patterns, multi-tier clinical validation protocols, and real-time safety monitoring specifically calibrated to pharmacy workflow characteristics reducing modernization failure rates by 50-70% while maintaining continuous clinical operations—a unified contribution not previously established in healthcare informatics literature. Healthcare enterprises embracing these evidence-based models can leverage new capabilities of AI-augmented clinical decision support, predictive analytics of medication adherence, and automation of prior authorization to move pharmacy functions from reactive transaction-based operations to proactive patient care functions, enabling innovation that improves underlying operations for new healthcare service delivery models focusing on distributed clinical care, real-time clinical workflows, and patient-centered medication management throughout complex health enterprise ecosystems where methodological rigor and cross-technical and clinical collaboration serve as foundational enablers of sustainable transformation success.

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