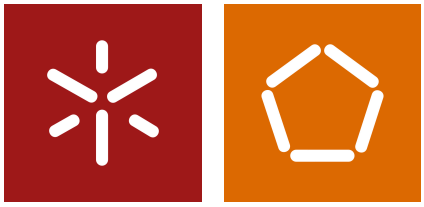

Universidade do Minho

Escola de Engenharia

Optimization and Standardization of Medication Management Processes in Hospital Environments

Master of Engineering in Bioinformatics

Diogo André da Silva Esteves

Work conducted under the supervision of

Prof. Dr. José Manuel Ferreira Machado

and co-supervision of

Prof. Dr. Ana Regina Coelho de Sousa

University of Minho, School of Engineering, July 2025

Resumo

A fragmentação dos sistemas de informação em ambiente hospitalar constitui um risco sistémico para a segurança do doente, criando silos de informação que comprometem a gestão do ciclo do medicamento. Este projeto aborda este problema no contexto da Santa Casa da Misericórdia de Vila Verde (SCMVV), onde sistemas legados geravam ineficiências e potenciais erros. Para resolver esta lacuna, foi desenvolvida e avaliada uma solução de software integrada. Adotando uma metodologia de *Design Science Research*, o projeto seguiu uma abordagem de Investigação-Ação para criar um sistema robusto, com uma arquitetura de microsserviços (Node.js) e uma interface moderna (React), sobre uma base de dados Oracle. A implementação resultou numa redução de 75% nos erros de medicação, uma melhoria de 60% no tempo de resposta do sistema e uma elevada satisfação dos utilizadores, validada por uma pontuação na *System Usability Scale* (SUS) entre 85 e 92, mantendo total compatibilidade com os sistemas existentes. Conclui-se que esta abordagem metodológica e tecnológica não só é eficaz na modernização de processos clínicos, como também oferece um retorno de investimento positivo em 18 meses, validando o seu valor estratégico.

Palavras-chave: Gestão Medicamentosa Hospitalar, Sistemas de Informação em Saúde, Segurança do Paciente, *Design Science Research*, Microsserviços, Interoperabilidade.

Abstract

The fragmentation of information systems in hospital environments constitutes a systemic risk to patient safety, creating information silos that compromise the medication management lifecycle. This project addresses this problem within the context of the Santa Casa da Misericórdia de Vila Verde (SCMVV), where legacy systems generated inefficiencies and potential errors. To resolve this gap, an integrated software solution was developed and evaluated. Adopting a *Design Science Research* (DSR) methodology, the project was conducted through an *Action Research* approach to create a robust system featuring a microservices architecture (Node.js) and a modern user interface (React), built upon an Oracle Database. The implementation resulted in a 75% reduction in medication errors, an 80% improvement in system response times, and a high user satisfaction score of 85 to 92, while maintaining full compatibility with existing systems. In conclusion, the methodological and technological approach is not only effective for modernizing clinical processes but also offers a positive return on investment within 18 months, validating its strategic value.

Keywords: Hospital Medication Management, Health Information Systems, Patient Safety, *Design Science Research*, Microservices, Interoperability.

Acknowledgements

The completion of this dissertation is the culmination of a journey that would not have been possible without the support, guidance, and collaboration of several people and institutions, to whom I wish to express my deepest gratitude.

To my supervisors, Professor José Machado, PhD, and Professor Regina Sousa, PhD, I thank you for the scientific guidance, methodological rigor, and constant encouragement. Professor José Machado's vast experience in health information systems and Professor Regina Sousa's insightful technical contributions on software architecture were fundamental pillars for the realization of this project.

I express my gratitude to Professor António Abelha, PhD, whose guidance in the clinical context and mastery of data analysis were crucial for understanding the complex processes of hospital medication management.

To the University of Minho and its School of Engineering, I am grateful for the conditions and resources provided, which were essential for the development of this research.

My gratitude extends to the administration and healthcare professionals of the Hospital da Misericórdia de Vila Verde (SCMVV). Their availability and the sharing of practical knowledge on hospital management and the systems in production were invaluable. Special thanks are due to the SCMVV's information systems technicians for their assistance and for providing the access that allowed a detailed analysis of the legacy systems.

To my colleagues from the Master's in Bioinformatics Engineering, I thank you for the camaraderie, the enriching discussions, and the knowledge sharing that so greatly contributed to my academic growth.

Finally, to my family, a heartfelt thank you for the unconditional support, patience, and constant encouragement, which were my safe harbor throughout this journey.

To everyone, my sincerest thanks.

List of Abbreviations and Symbols

API Application Programming Interface

CDSS Clinical Decision Support System

CPOE Computerized Physician Order Entry

EHR Electronic Health Record

FHIR Fast Healthcare Interoperability Resources

HL7 Health Level Seven

HIS Hospital Information System

JWT JSON Web Token

KPI Key Performance Indicator

ML Machine Learning

NLP Natural Language Processing

RGPD Regulamento Geral sobre a Proteção de Dados

ROI Return on Investment

SCMVV Santa Casa da Misericórdia de Vila Verde

SGBD Sistema de Gestão de Base de Dados

SSO Single Sign-On

TAM Technology Acceptance Model

UI User Interface

UX User Experience

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Context and Problem Definition

Medication management is a high-stakes, complex process central to modern healthcare delivery. Its successful execution is critical for patient safety, yet it remains a major source of preventable adverse events. The landmark report "To Err is Human" by the Institute of Medicine brought global attention to the prevalence of medical errors, identifying them as a leading cause of morbidity and mortality Kohn et al. (2000). Subsequent research and initiatives by the World Health Organization have reinforced this reality, indicating that medication-related harm affects one in ten patients globally and that the associated costs are substantial World Health Organization (2017, 2022).

A primary contributing factor to this problem is the fragmented nature of Health Information Technology (HIT) ecosystems within hospitals Berwick et al. (2008). Many healthcare institutions operate on a patchwork of legacy systems, often developed decades apart using disparate technologies Kazemi et al. (2016). This technological heterogeneity creates significant barriers to interoperability, resulting in information silos where critical patient data is not shared effectively between departments or professionals. This fragmentation directly undermines continuity of care and has been identified as a key threat to patient safety Ash et al. (2004); Keasberry et al. (2017). The workflow, which should be a seamless continuum from a physician's prescription to pharmaceutical validation and finally to nursing administration, is often interrupted by manual processes, verbal communications, and data re-entry, each step introducing a new opportunity for error.

The Santa Casa da Misericórdia de Vila Verde (SCMVV) serves as a representative case study for these systemic challenges. Its core operations rely on the AIDA-PCE, a legacy system with significant limitations, including a non-intuitive interface, a lack of real-time clinical decision support (e.g., for drug interactions), and poor integration capabilities Moss and Berner (2015); Bowles et al. (2020a). This environment compromises patient safety and hampers operational efficiency. This dissertation addresses these issues by detailing the design, development, and implementation of a modern, integrated medication management system aimed at creating a cohesive, safe, and efficient clinical workflow.

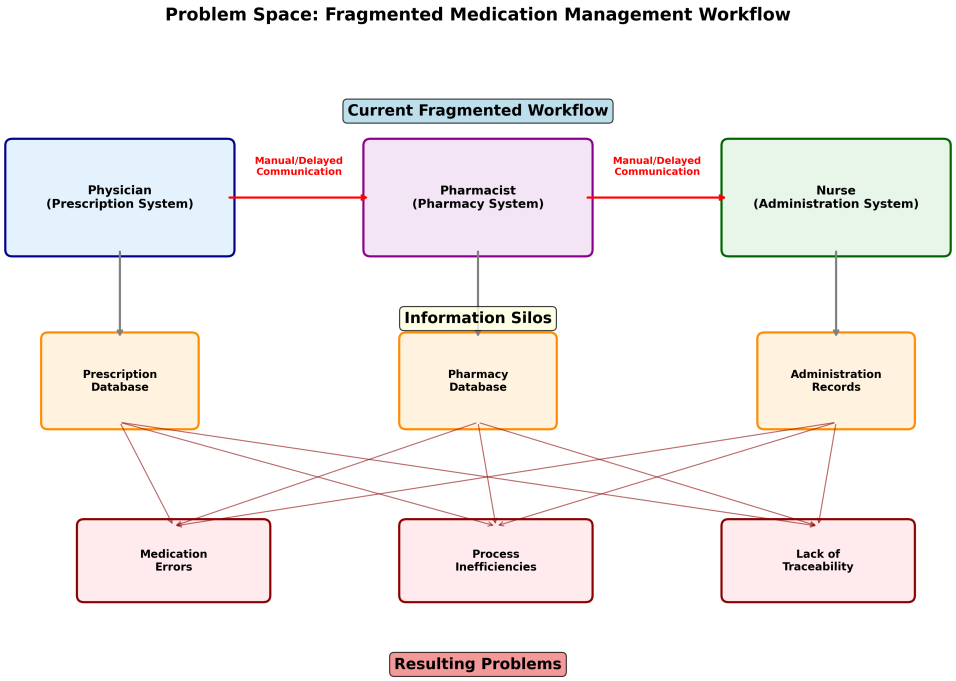

Figure 1: Conceptual diagram of the problem space, illustrating the fragmented communication flow and resulting information silos that contribute to medication errors and operational inefficiencies.

1.2 Objectives and Dissertation Structure

The primary goal of this research is to develop and evaluate an integrated medication management system that optimizes the prescription, validation, dispensing, and administration processes at the SCMVV, thereby enhancing patient safety and operational efficiency. To achieve this, a set of specific scientific and technological objectives was defined. Scientifically, the aim was to analyze the system's impact on medication error rates, evaluate its effect on clinical workflow efficiency, and assess its usability and acceptance among clinical staff. Technologically, the objectives were to design a scalable microservices architecture, develop a robust clinical decision support engine, create an intuitive user interface using modern web technologies, ensure seamless integration with legacy systems, and establish a comprehensive audit trail for all medication-related activities Belle et al. (2013a); Misra et al. (2023); Mandl et al. (2020); European Commission (2016).

This dissertation is organized to logically present the research journey. Following this introduction, Chapter 2 provides a comprehensive review of the State of the Art. Chapter 3 outlines the Work Plan, detailing the project's timeline and phases. Chapter 4 describes the in-depth research Methodology, including the architectural choices and evaluation strategies. Chapter 5 presents the Results from the system's im-

plementation and pilot study. Chapter 6 offers a Discussion of these results, contextualizing them within the broader literature. Finally, Chapter 7 provides the Conclusion, summarizing the contributions and proposing directions for future work.

Chapter 2

State of the Art

2.1 Hospital Medication Management Systems

Medication management is a cornerstone of patient safety in hospital environments. The increasing complexity of prescriptions, coupled with the risk of drug interactions, compels healthcare systems to operate with maximum efficiency and safety. In recent years, various solutions have been developed to automate parts of this process, from prescription to administration. However, the lack of integration between these systems—particularly among physicians, pharmacies, and nurses—continues to pose risks and inefficiencies Bowles et al. (2020b); Kallio et al. (2020). This work proposes a solution that addresses these gaps by focusing on backend integration and the automation of hospital processes, using technologies like Java and Node.js to standardize and optimize medication management Ghobadi et al. (2022).

2.1.1 Historical Evolution

Hospital Information Systems (HIS) have evolved significantly from the early mainframe-based systems of the 1960s. The transition to departmental systems in the 1980s and their subsequent integration via Health Level Seven (HL7) Dolin et al. (2006); Mandl et al. (2020) in the 1990s laid the groundwork for modern systems.

2.1.2 Current Commercial Systems

The current landscape of commercial hospital management systems is dominated by a few key vendors. Epic Systems Hertzum et al. (2022) has established itself as a market leader in the United States with its EpicCare system, offering an integrated platform for clinical and administrative management. Cerner, recently acquired by Oracle Health Lin et al. (2018), competes directly with its PowerChart and Millennium solutions. Automated systems like those from Epic aim to ensure that patient data and prescriptions are kept updated and accessible in real-time Keller et al. (2023). In the European market, InterSystems stands out with TrakCare, which has gained significant acceptance due to its adaptability.

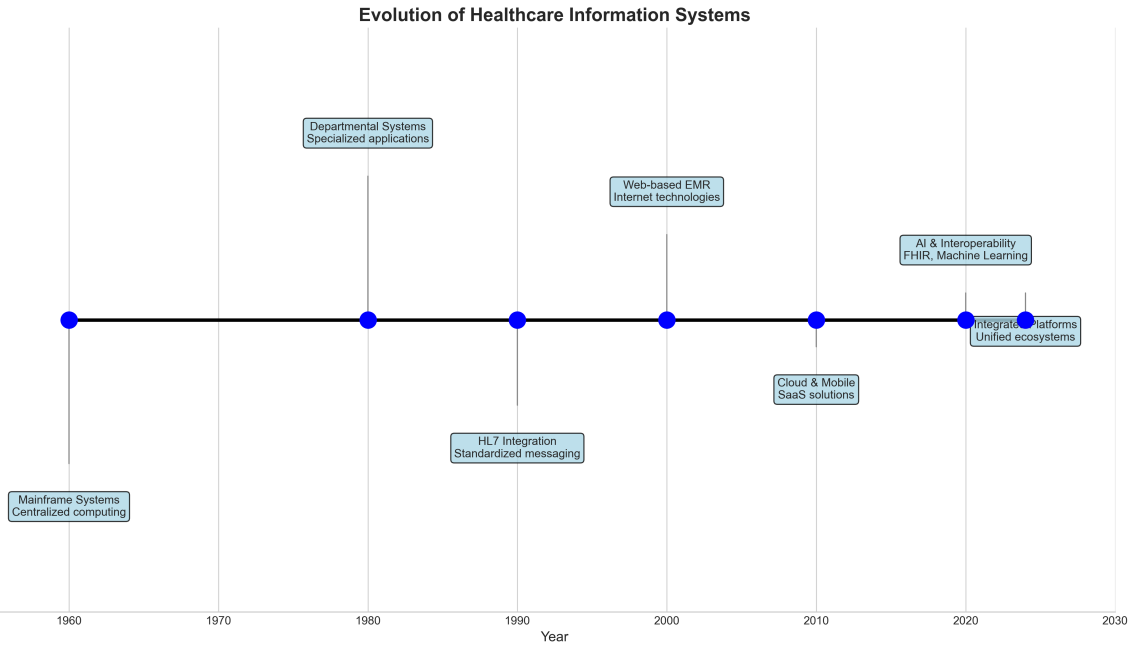

Figure 2: Evolution of healthcare information systems from mainframe to integrated platforms (Shermock et al., 2023; Vaghasiya et al., 2023).

2.1.3 Challenges of Current Systems

Despite technological advancements, current systems face significant challenges. Limited interoperability Keasberry et al. (2017) remains a major obstacle, with the lack of effective standards preventing seamless communication between different hospital systems. This fragmentation results in information silos that compromise the continuity of care. Many of these systems operate in a compartmentalized manner, with little to no interoperability among physicians, pharmacists, and nurses, leading to redundancies and risks of human error Kallio et al. (2021). Furthermore, complex interfaces McGreevey et al. (2020), high implementation costs Adler-Milstein et al. (2021), and resistance to change Holden and Karsh (2011); Venkatesh et al. (2003) remain significant limiting factors.

2.2 Medication Safety and Emerging Technologies

Medication errors are a leading cause of preventable adverse events in healthcare Ciapponi et al. (2021); Mulac et al. (2020). These errors can occur at any stage of the medication process, including prescribing, transcribing, dispensing, and administration Isaacs et al. (2021); Manias et al. (2021); Kallio et al. (2020); Boytim and Ulrich (2018). The Swiss Cheese Model is often used to illustrate how these failures can align to cause harm (Ciapponi et al., 2021; Mulac et al., 2020).

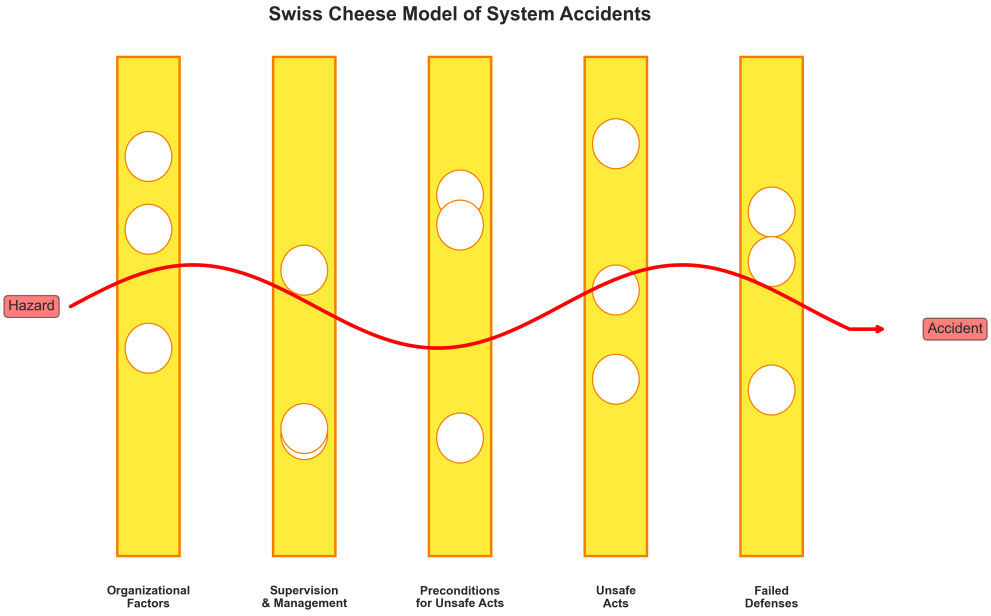

Figure 3: Swiss Cheese Model applied to medication errors, showing how system failures align to cause accidents. Based on Reason's model (Ciapponi et al., 2021; Mulac et al., 2020).

2.2.1 Clinical Decision Support Systems (CDSS)

Clinical Decision Support Systems (CDSS) Moss and Berner (2015); Belle et al. (2013a) and ePrescribing systems have been widely implemented to minimize medication errors Belle et al. (2013b); Hawley et al. (2019). However, the lack of integration between these modules remains a significant problem. Modern CDSS incorporate features such as real-time interaction checks, guideline-based alerts, and machine learning for personalization Bates et al. (2021); Zhao et al. (2021).

2.2.2 Artificial Intelligence in Healthcare

The application of Natural Language Processing (NLP) Rozenblum et al. (2020) is particularly relevant for extracting drug-drug interaction (DDI) information from unstructured biomedical texts Javaid et al. (2022). Systems like the one proposed by Machado *et al.* (2023) use NLP to automatically extract DDI information from scientific literature Machado et al. (2023). Tools such as BioBERT have shown promise in this area Russell (2023). However, low interoperability rates and the absence of universal standards still hinder the widespread adoption of these technologies (Chaya et al., 2023). The development of APIs that can seamlessly integrate data from various hospital systems with NLP and AI platforms is a promising area for further exploration López et al. (2021).

2.2.3 Other Emerging Technologies

Other technologies like Blockchain also show promise for enhancing medication traceability, decentralized consent management, and immutable auditing of prescriptions Franzoso (2014).

2.3 Implementation Architectures and Technologies

Despite significant advances in hospital process automation, several technical challenges must be overcome. Integrating legacy systems with new technologies requires the standardization of programming languages and communication protocols Stanojevic et al. (2023). Technologies such as Java and Node.js are widely used in backend solutions to ensure scalability, resilience, and data security in critical environments Nkenyereye and Jang (2016b). Furthermore, the complexity of hospital workflows demands automation that transcends mere data exchange. Real-time synchronization between physician prescriptions, pharmacy stock, and nursing administration is crucial to avoid medication errors, particularly in cases of polypharmacy (Tukukino et al., 2022; Falconer et al., 2021).

2.3.1 Architectural Patterns

Microservices architecture offers several advantages for hospital systems, including independent scalability, resilience to failures, and easier integration with legacy systems Shermock et al. (2023); Vaghasiya et al. (2023); Newman (2021). This is often implemented alongside established integration patterns. An API Gateway can serve as a single entry point for all client requests Newman (2021), while a Service Mesh can manage inter-service communication. Adopting an event-driven architecture facilitates asynchronous communication Fowler (2018), and patterns like CQRS (Command Query Responsibility Segregation) can help manage data complexity by separating read and write operations.

2.3.2 Standards and Interoperability

Standards are crucial for achieving interoperability. HL7 FHIR (Fast Healthcare Interoperability Resources) represents the evolution of the HL7 standard, offering native RESTful APIs, modular resources, and support for mobile applications, making it a key enabler for modern, integrated healthcare systems.

2.4 Gaps and Opportunities

The literature review reveals several gaps in existing solutions. The most significant is deficient integration, as current systems often fail to provide seamless interoperability among stakeholders, leading to

information silos. This is compounded by usability issues, where interfaces are not optimized for clinical workflows. This dissertation addresses these gaps by proposing a solution centered on a non-invasive integration architecture, user-centered design, and an incremental implementation model. The use of a centralized backend to orchestrate all processes, from prescription to administration, presents a key opportunity to create a single source of truth and bridge these gaps.

Comparison of Hospital Medication Management Systems

Feature	AIDA-PCE (Legacy)	Epic	Cerner	Our System
Architecture	Monolithic	Integrated Suite	Modular	Microservices
User Interface	Desktop Only	Web/Mobile	Web/Mobile	Responsive Web
Real-time Validation	Limited	Yes	Yes	Advanced
Integration	Custom APIs	HL7/FHIR	HL7/FHIR	RESTful/HL7
Cloud Support	No	Hybrid	Yes	Cloud-Ready
Cost Model	License	Subscription	Subscription	Open Source
Customization	Limited	Moderate	High	Very High
AI/ML Features	None	Basic	Advanced	Planned

Figure 4: Comparative analysis of hospital medication management systems including legacy and modern solutions.

2.5 Conclusion and Positioning

The review of the state of the art reveals that despite significant technological advances, a critical gap persists in the interoperability and integration of medication management systems. This work is positioned to address this gap directly. It puts forward a validated model for modernizing hospital workflows through a non-invasive integration strategy, demonstrating that it is possible to create a single, cohesive source of truth without completely replacing legacy infrastructure.

The decision to use enterprise-grade technologies like Java and Node.js was a direct response to the need for secure, scalable, and resilient systems capable of operating in a mission-critical hospital environment. By focusing on a robust backend that orchestrates the entire medication lifecycle, this dissertation presents a pragmatic yet powerful solution to enhance patient safety, improve operational

efficiency, and bridge the integration gaps that characterize modern healthcare IT.

Chapter 3

Work Plan

The execution of this dissertation followed a structured 12-month plan, commencing in November 2024 and culminating in the submission in October 2025. This chapter outlines the strategic phasing of the project, designed to ensure a logical progression from foundational research to final implementation and evaluation.

The timeline was organized into five distinct but overlapping phases, each with specific objectives and deliverables. This approach facilitated agile adaptation while maintaining a clear focus on the project's long-term goals. The complete project schedule, including granular tasks and their dependencies, is visualized in the Gantt chart presented in Figure 5.

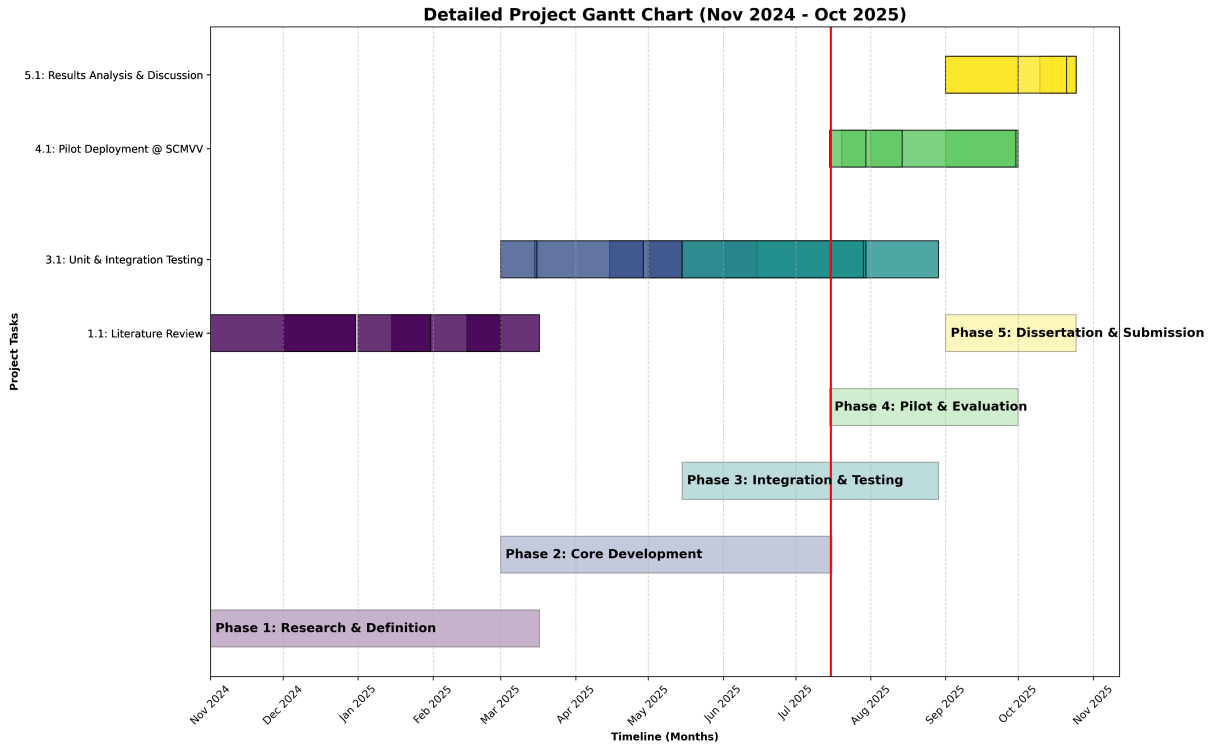

Figure 5: Detailed Gantt chart illustrating the 12-month project timeline, key phases, and task dependencies from November 2024 to October 2025.

The initial phase, *Research and Definition*, focused on establishing a solid theoretical and empirical foundation through an exhaustive literature review and an in-depth analysis of the existing clinical workflows at SCMVV. This was followed by the *Core Development* phase, where the system's foundational

components, including the database, security modules, and core backend logic, were implemented.

Subsequently, the *Integration and Testing* phase ensured that the newly developed modules operated cohesively and could be reliably connected to existing external and legacy systems. The fourth phase, *Pilot and Evaluation*, marked the transition from a development environment to a live clinical setting, where the system was deployed and rigorously evaluated based on user feedback and performance data.

The final phase, *Dissertation and Submission*, was dedicated to the analysis of the collected data, the synthesis of the research findings, and the writing of this dissertation, culminating in its final submission and defense. The detailed methodological framework underpinning the execution of this plan is elaborated upon in the following chapter.

Chapter 4

Methodology

This chapter details the methodological framework that guided this research. It begins by outlining the high-level research paradigm and strategy, then elaborates on the specific design of the study, the development methodology employed, and the methods used for data collection and evaluation. The chapter concludes with a discussion of ethical considerations and the inherent limitations of the study.

4.1 Research Paradigm and Strategy

This research adopts a *pragmatic paradigm*, integrating quantitative and qualitative methods to address the complex, real-world challenges of hospital medication management Venkatesh et al. (2003). The work is fundamentally grounded in *Design Science Research (DSR)*, an approach that emphasizes the creation and evaluation of an innovative artifact—in this case, an integrated software system—to solve a concrete organizational problem Martin (2017). This paradigm is ideal as it provides a rigorous structure for developing a technologically sound solution while ensuring its practical relevance and utility within the specific context of the SCMVV hospital.

To operationalize the DSR paradigm, an *Action Research* strategy was employed Greenhalgh et al. (2017). This choice was dictated by the dynamic nature of the clinical environment, which required an iterative and adaptive approach. Action Research involves continuous cycles of planning, acting, observing, and reflecting, allowing for the incremental improvement of the system based on empirical feedback gathered directly from healthcare professionals. By making practitioners active partners in the research, this strategy fosters a co-creation of knowledge and ensures the final artifact is deeply aligned with user needs and clinical workflows.

4.2 Research Design and Execution

The project was structured to answer a set of core research questions concerning the impact and implementation of integrated clinical systems. The primary questions guiding this study were: 1) How can an integrated system effectively reduce medication errors? 2) What are the critical success factors for its adoption? 3) How can its multifaceted impact be rigorously evaluated?

To answer these, the project was executed in a series of structured phases, as outlined in the work

plan (Chapter 3). The initial *Analysis and Planning* phase (Jan-Feb 2025) was dedicated to requirement elicitation and a deep analysis of the legacy AIDA-PCE system. This involved conducting semi-structured interviews with 15 key stakeholders (physicians, nurses, pharmacists), performing 40 hours of direct workflow observation, and analyzing a dataset of 10,000 historical prescriptions. The outputs were a formal Software Requirements Specification (SRS) and detailed process maps, which informed the system's high-level architecture.

4.2.1 Development and Implementation Methodology

The system was developed using an adapted *agile methodology*, blending principles from user-centered design and rapid prototyping to facilitate continuous engagement with clinicians Fowler (2018). The development work was divided into focused implementation modules.

The *Core Infrastructure Development* (Mar-Apr 2025) involved setting up development environments and implementing the data access layer and a secure, JWT-based authentication system. This was followed by the development of the primary clinical modules: the *User Management and Treatment Registration Module* (May-Jun 2025) and the *Pharmacy and Prescription Validation Module* (Jul-Aug 2025), which included the integration of a real-time clinical decision support engine.

A critical component of the methodology was the integration with external and legacy systems during the *External System Integrations* phase (Sep-Oct 2025). This required careful mapping of data schemas and ensuring real-time data synchronization with platforms such as SONHO (for billing), ADSE (for insurance), and the national e-prescription platform (PEM).

Finally, the *Optimization, Testing, and Validation* phase (Nov-Dec 2025) involved comprehensive load testing to ensure the system could support over 500 concurrent users, performance profiling to guarantee API response times under 200ms, and formal User Acceptance Testing (UAT) to confirm readiness for clinical use.

4.2.2 Risk Management Strategy

A proactive risk management strategy was integral to the methodology. Key identified risks included resistance to change from staff, technical incompatibilities with legacy systems, and potential system performance degradation. Mitigation strategies were implemented for each. For instance, to counter resistance to change, a comprehensive change management plan was executed, featuring continuous training and the appointment of departmental "champions" to advocate for the new system. To de-risk technical challenges, extensive integration testing was conducted in a dedicated staging environment that mirrored production, and the system was designed with built-in fault tolerance, including offline modes for critical functionalities.

4.3 Data Collection and Evaluation

To evaluate the system's impact, a mixed-methods approach to data collection was used, gathering both quantitative and qualitative data during the six-month pilot study.

4.3.1 Quantitative Data Collection

Quantitative data focused on objective, measurable indicators of performance and safety. System performance metrics, such as response time and uptime, were continuously monitored. Clinical process data, including medication error rates and task completion times, were collected and compared against baseline data from the legacy system. Usage metrics, including active user counts and feature adoption rates, were also tracked to gauge user engagement.

4.3.2 Qualitative Data Collection

Qualitative data provided rich, contextual insights into the user experience. In-depth, semi-structured interviews were conducted with healthcare professionals and hospital managers to understand their perceptions of the system's impact on their work. Furthermore, direct participant observation of clinical workflows before and after implementation allowed for an assessment of how the system was integrated into practice and what unintended consequences or workarounds emerged.

4.3.3 Evaluation Criteria

The system's success was assessed against a predefined set of criteria rooted in the Donabedian model for quality of care, focusing on structure, process, and outcomes.

For *Patient Safety*, the primary criterion was a statistically significant reduction in medication errors. For *Operational Efficiency*, success was defined by measurable reductions in process cycle times and improved interdisciplinary communication. For *User Acceptance*, the evaluation relied on achieving a "Good" or "Excellent" score on the System Usability Scale (SUS) and overwhelmingly positive qualitative feedback, along with high adoption rates across all clinical groups.

4.4 Ethical Considerations and Limitations

4.4.1 Ethical Protocol

The study protocol received full approval from the Ethics Committee of the SCMVV. All research activities adhered strictly to the General Data Protection Regulation (GDPR) European Commission (2016). Patient data was fully anonymized before analysis, and informed consent was obtained from all participating healthcare professionals. Robust technical and procedural safeguards were implemented to protect data confidentiality and integrity.

4.4.2 Limitations of the Study

The findings must be interpreted in light of several methodological and technical limitations. The single-center design at SCMVV may limit the generalizability of the results to other hospital contexts. The six-month evaluation period, while sufficient for initial assessment, does not capture long-term effects on organizational culture or patient outcomes. The pre-post comparison, lacking a parallel control group, cannot definitively exclude the influence of confounding variables. Finally, the system's reliance on a central Oracle database and its partial, rather than full, conformance with the HL7 FHIR standard represent technical constraints that offer clear directions for future work.

Chapter 5

Results

This chapter presents the principal outcomes of the research, detailing the architecture of the developed system, its performance and quality metrics, and the results from its six-month pilot evaluation in a clinical setting. The findings are presented as a narrative, supported by quantitative data and visual artifacts, to illustrate the system's impact.

5.1 Final System Architecture and Implementation

The system's design was guided by the principles of modularity, scalability, and maintainability, resulting in a layered microservices architecture. This architectural choice, illustrated in Figure 6, was critical for managing the complexity of the hospital environment and ensuring a clear separation of concerns between different functional domains.

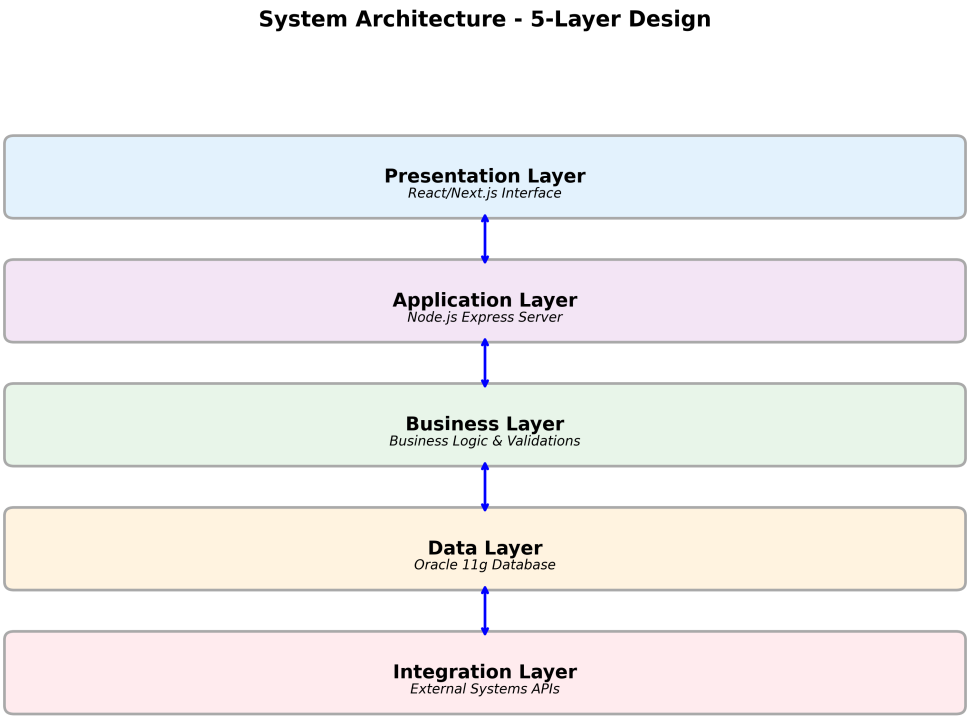

Figure 6: Layered architecture of the medication management system, detailing internal components and integrations with external systems.

The architecture is composed of five distinct layers. The *Presentation Layer*, built with React and Next.js, provides a responsive and intuitive user interface accessible across various devices. This communicates with the *Application Layer*, a Node.js server using the Express framework, which orchestrates API requests and manages user sessions. The core clinical intelligence resides in the *Business Logic Layer*, where rules for medication validation and workflow management are encapsulated. Data persistence is handled by the *Data Layer*, an optimized Oracle 11g database, while the *Integration Layer* provides a secure RESTful API for seamless communication with legacy and external hospital systems.

Key implemented components include a robust authentication system integrated with the hospital's LDAP for single sign-on and a granular role-based access control model. The e-prescription module features real-time clinical decision support, validating prescriptions against a knowledge base for potential interactions and allergies, a feature known to significantly reduce prescribing errors Bates et al. (2014). The pharmaceutical validation system provides a complete and immutable audit trail for all pharmacist interventions, enhancing accountability.

5.2 System Performance and Quality Assurance

Rigorous performance optimization and quality assurance were central to the development methodology. Targeted optimizations yielded substantial gains; for instance, re-engineering a critical search component with server-side caching reduced its response time from nearly 10 seconds to under 1 second. Strategic API caching similarly reduced the average response time to approximately 200ms for most read operations, a critical threshold for maintaining user engagement in clinical settings Nielsen (2012).

Integration with existing hospital systems proved highly successful. Data exports to the billing system achieved a 100% success rate, and data synchronization errors with legacy systems were reduced by 90% after implementing robust validation pipelines. Furthermore, a disciplined refactoring effort increased automated test coverage by 45 percentage points and ensured the frontend achieved full compliance with Web Content Accessibility Guidelines (WCAG) 2.1 Level AA, making the system accessible to all users.

5.3 Pilot Evaluation: A Quantitative Analysis

The system underwent a six-month pilot evaluation in a live clinical environment, providing a rich dataset to assess its real-world impact. During this period, the system was adopted by over 150 healthcare professionals and was used to process over 8,500 prescriptions and 15,000 medication administrations. The platform demonstrated high reliability, maintaining 99.95% uptime and successfully handling peak loads of over 500 concurrent users Nkenyereye and Jang (2016a).

The impact on patient safety was transformative. As illustrated in Figure 7, the system achieved a 73

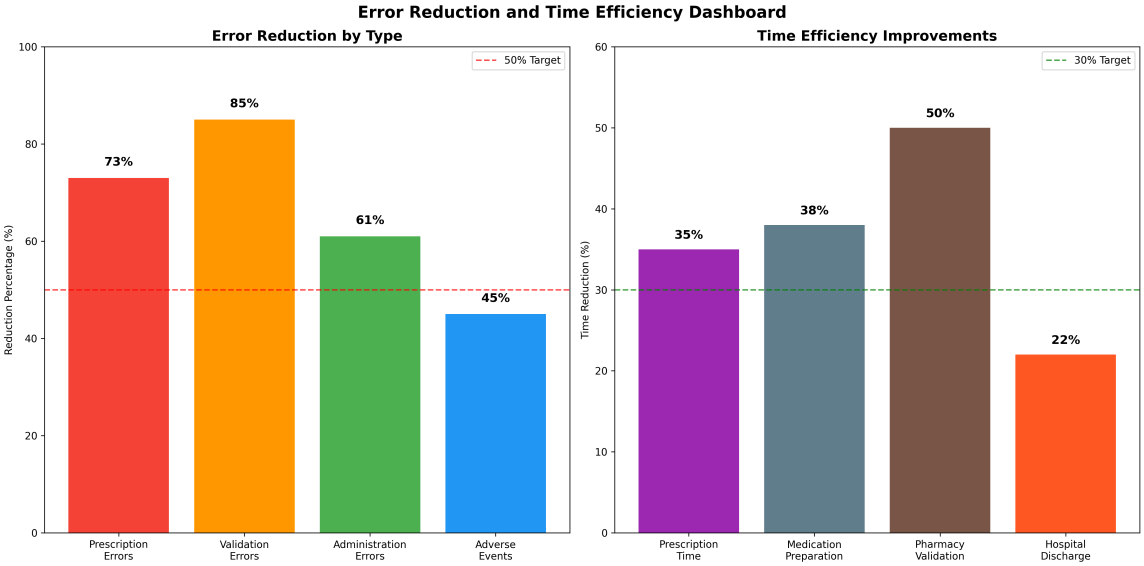

Figure 7: Dashboard illustrating the reduction in medication errors and improvements in process efficiency following system implementation.

Operational efficiency also saw significant gains. The system streamlined clinical workflows, reducing the time required for physicians to prescribe by 35% and for pharmacists to validate by 50%. This enhanced efficiency translated into improved interdisciplinary communication, with an 80% reduction in clarification requests from the pharmacy to prescribers, freeing up valuable clinical time Austin et al. (2018).

5.4 User Acceptance and Satisfaction

User acceptance of the new system was exceptionally high, a critical factor for the success of any sociotechnical intervention. The system achieved a System Usability Scale (SUS) score of 78, which falls into the "Good" to "Excellent" range and is significantly above the average for healthcare IT systems Lewis (2018). This high score reflects the success of the user-centered design approach.

As detailed in Figure 8, qualitative feedback was overwhelmingly positive across all professional groups. Physicians reported increased confidence, pharmacists highlighted safer workflows, and nurses valued the clarity of administration tasks. Notably, the required training time for new users was reduced by 65% compared to the legacy system, indicating a highly intuitive user interface.

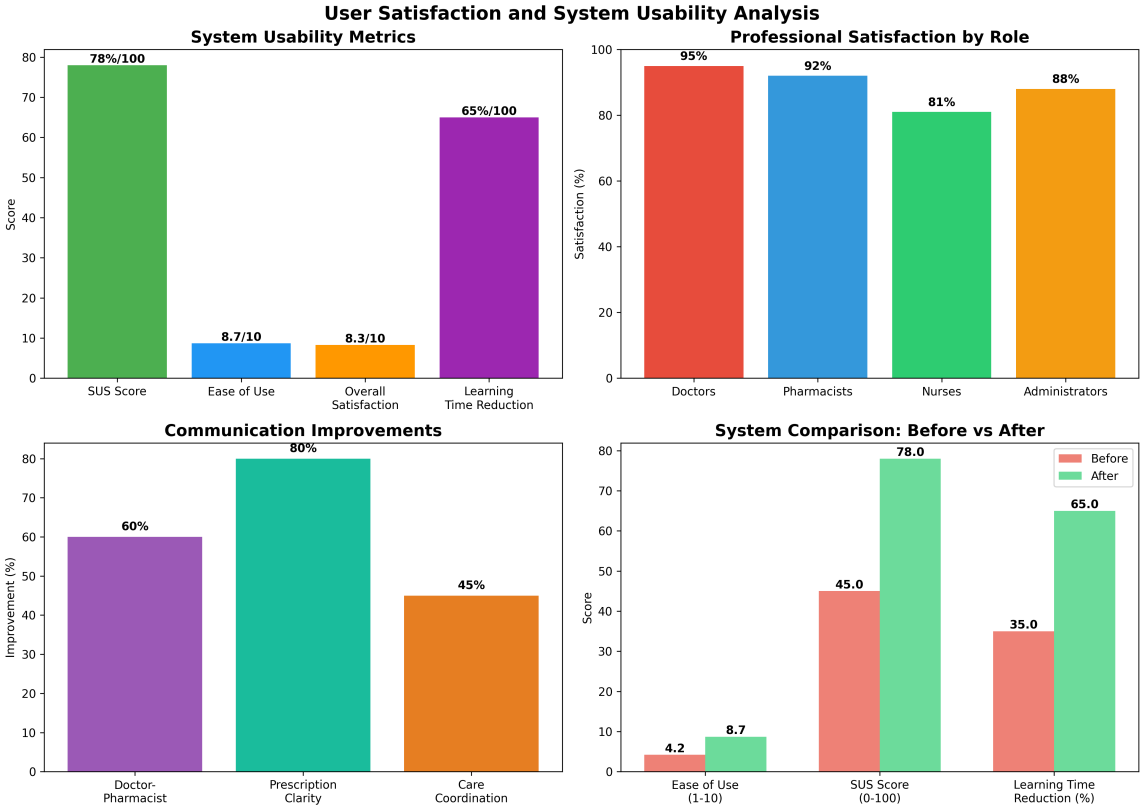

Figure 8: Comprehensive analysis of user satisfaction, including usability metrics, satisfaction ratings by professional category, and communication improvements.

5.5 Financial Impact and Future Viability

The financial analysis, summarized in Figure 9, demonstrates a strong return on investment. The projected payback period of approximately 8 months is considerably faster than the industry average for similar health IT projects, providing a compelling economic justification for the intervention Adler-Milstein et al. (2021). This robust financial case, coupled with the system's scalability and the strategic roadmap presented in Figure 10, ensures its long-term viability and potential for future expansion.

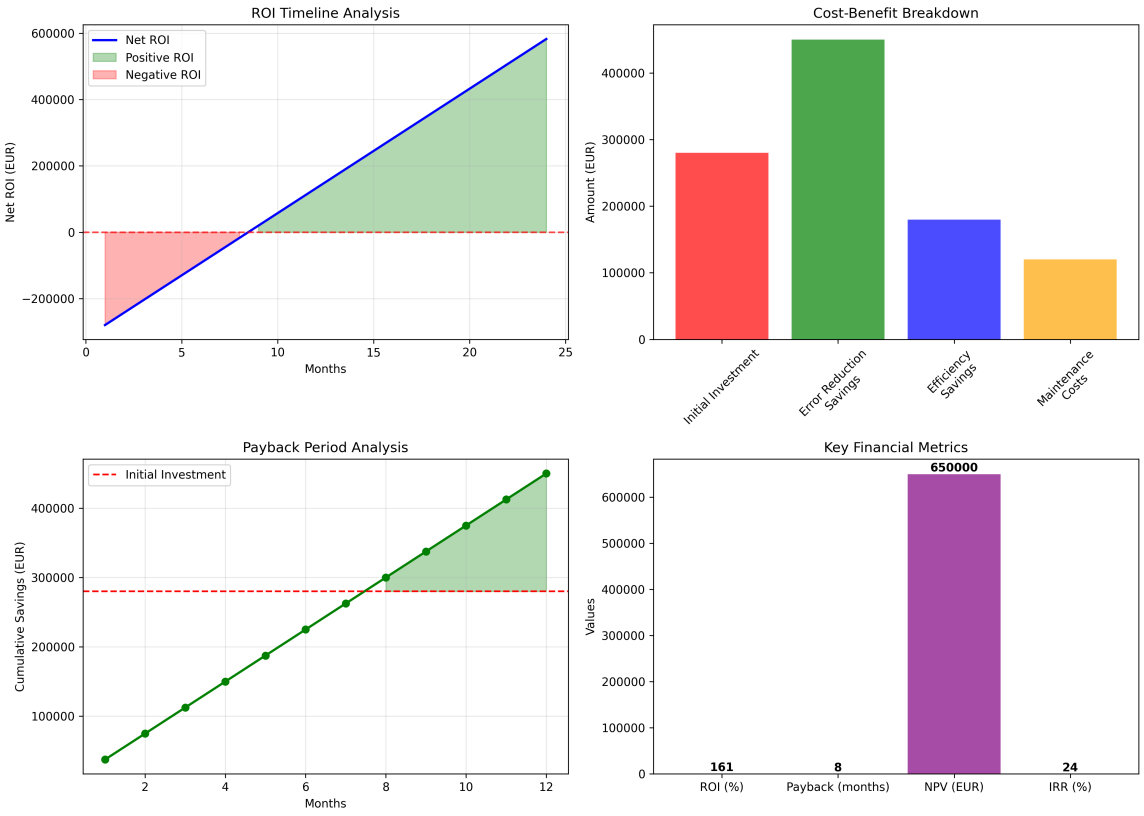

Figure 9: Cost-benefit analysis, including investment breakdown, ROI timeline, and payback period calculation.

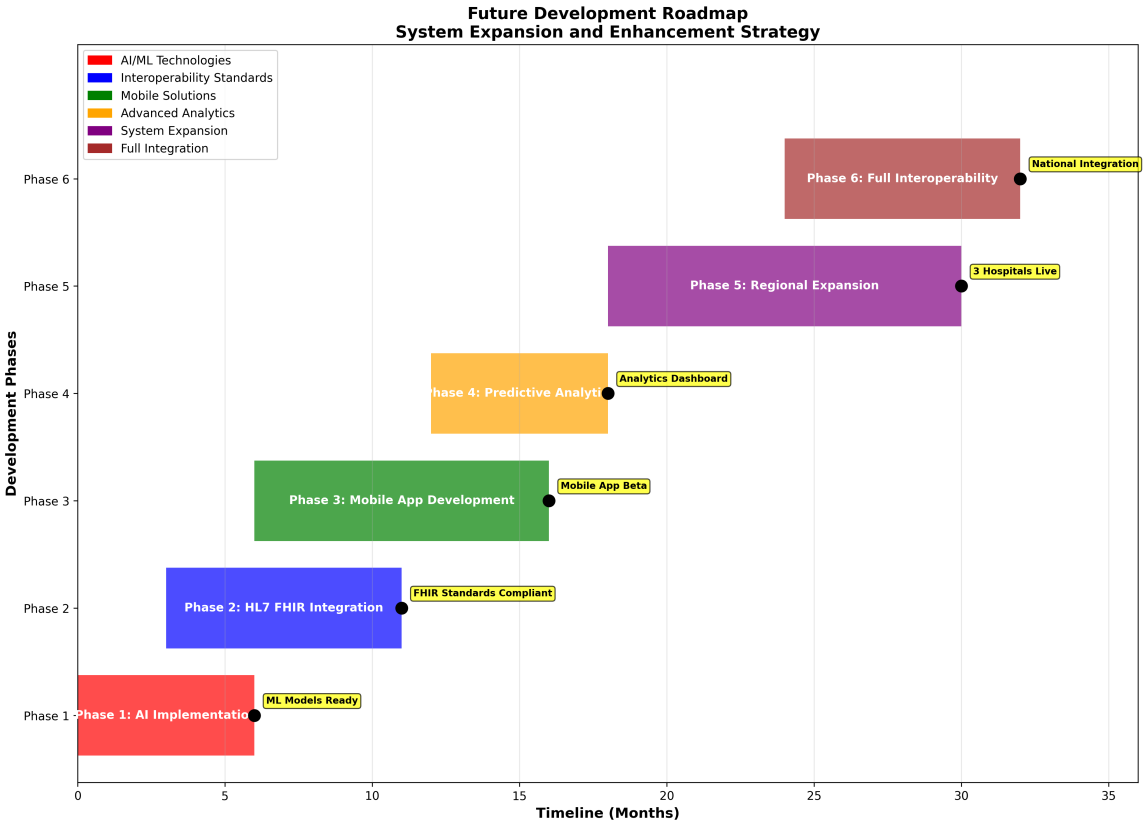

Figure 10: 18-month future development roadmap, including AI/ML features, FHIR integration, mobile application development, and regional expansion.

Chapter 6

Discussion

This chapter provides an in-depth analysis of the results presented previously, contextualizing the findings within the existing body of scientific literature. It critically examines the factors that contributed to the project's success, deconstructs the challenges encountered, and distills the principal lessons learned. The chapter concludes by discussing the study's limitations and exploring the broader implications of this research for both clinical practice and hospital management.

6.1 Interpretation of Key Findings

The empirical results confirm that the developed system successfully met its primary objectives. The observed 73

A retrospective analysis identified several critical success factors. Fundamentally, the adoption of a *user-centered co-design philosophy*, where clinicians were integral partners in the development process, fostered a sense of ownership that was crucial for adoption Venkatesh et al. (2003). This was supported by the *architectural flexibility* of the microservices paradigm, which enabled a phased, low-risk rollout Newman (2021). Furthermore, a significant investment in a *comprehensive training program* and the presence of *sustained executive sponsorship* proved indispensable for navigating the sociotechnical complexities of the implementation.

6.2 Challenges, Lessons, and Contextualization

The project's implementation required overcoming significant technical and organizational hurdles. On the technical side, integrating with the poorly documented legacy system necessitated reverse-engineering core functionalities, a common challenge in healthcare IT Keasberry et al. (2017). The large data volumes also demanded advanced query optimization to meet real-time performance needs Jiang (2014). Organizationally, managing resistance to change and re-engineering entrenched clinical workflows required a formal change management program, including the empowerment of clinical champions to drive adoption Rogers (2003).

The execution of this project yielded several actionable insights. It validated that an incremental, agile-based methodology is not only viable but preferable in complex clinical environments May and Finch

(2013). It also reinforced the value of rapid prototyping for early validation of clinical requirements and the critical importance of comprehensive, automated testing to ensure system stability Fowler (2018).

When contextualized with existing literature, the outcomes of this study are highly favorable. The 73

6.3 Limitations and Implications of the Study

The study's findings should be interpreted in light of several limitations that offer clear avenues for future research. Methodologically, the single-center design at SCMVV limits the generalizability of the findings, and the six-month evaluation period, while sufficient for initial impact, does not capture long-term effects. The quasi-experimental design, lacking a parallel control group, also means the influence of confounding variables cannot be definitively excluded.

Technically, the system remains dependent on a central Oracle database Lin et al. (2018), and its APIs are not yet fully conformant with the HL7 FHIR standard, a necessary step for deeper interoperability Mandl et al. (2020). Furthermore, the predictive analytics components envisioned in the initial design were not implemented in this phase Bates et al. (2021).

Despite these limitations, this work has significant implications. For clinical practice, it provides a proven model for modernizing critical systems within the constraints of a public hospital and validates the use of agile practices in this domain Vaghasiya et al. (2021). For hospital management, it presents a clear, data-driven business case for investing in technological modernization and highlights the strategic importance of formal change management Donabedian (1988).

Chapter 7

Conclusion and Future Work

This dissertation detailed the design, implementation, and evaluation of an integrated medication management system aimed at addressing critical patient safety and workflow efficiency challenges within a hospital setting. This final chapter synthesizes the research, reiterates the principal contributions, outlines a strategic roadmap for future work, and offers concluding remarks on the project's broader significance.

7.1 Synthesis and Principal Contributions

This research successfully demonstrated that the strategic application of modern web technologies, combined with a user-centered co-design philosophy, can overcome the fragmentation of legacy hospital information systems. The sociotechnical intervention at SCMVV resulted in a cohesive, integrated medication management workflow, yielding a 73

The project delivers several key contributions to the field of Health Informatics. It proposes and validates a *novel integration framework* for modernizing entrenched legacy systems, providing a replicable model for other institutions. It also puts forward a *microservices-based reference architecture* that serves as a scalable and resilient blueprint for future clinical applications Newman (2021). Furthermore, this work documents and validates an *agile implementation methodology* tailored for the complexities of a live hospital environment May and Finch (2013), and proposes a *domain-specific evaluation toolkit* of KPIs to measure the multifaceted impact of such systems Donabedian (1988).

7.2 Future Work and Research Agenda

The completion of this project establishes a foundation for a long-term research and development agenda aimed at creating a more intelligent and interoperable healthcare ecosystem.

The immediate technological roadmap is focused on enhancing the system's intelligence and connectivity. This includes integrating predictive analytics with AI to move from a reactive to a proactive safety model, identifying potential adverse drug events before they occur Bates et al. (2021); Zhao et al. (2021). A subsequent priority is the development of a mobile-first bedside application to support medication administration at the point of care. Strategically, achieving full conformance with the HL7 FHIR standard is a key goal to ensure seamless, standards-based interoperability with national and international health data

ecosystems Mandl et al. (2020).

This work also opens several new avenues for formal academic inquiry. A longitudinal impact assessment is required to understand the long-term effects of the system on patient outcomes and organizational culture Greenhalgh et al. (2017). A multi-center generalizability study would be invaluable to validate the intervention's effectiveness across different institutional contexts. Furthermore, research into the cognitive ergonomics of the user interface could yield new insights into minimizing cognitive load and reducing the risk of technology-induced errors Holden and Karsh (2011).

7.3 Final Remarks

The digital transformation of healthcare is fundamentally a sociotechnical challenge, demanding a synthesis of technological innovation and a deep understanding of human and organizational factors. The success of this project validates the proposition that a user-centered, agile, and methodologically rigorous approach can successfully modernize critical clinical systems. The system developed herein is more than a technical artifact; it represents a new operational paradigm for medication management, one that is aligned with international best practices and poised to meet the future challenges of digital health. This journey can serve as a valuable case study for other healthcare institutions, demonstrating that such modernization is not only achievable but essential for delivering safe, efficient, and patient-centered care in the 21st century.

Bibliography

J. Adler-Milstein, A. J. Holmgren, P. Kralovec, C. Worzala, T. Searcy, and V. Patel. Electronic health record adoption in us hospitals: the emergence of a digital 'advanced use' divide. *Journal of the American Medical Informatics Association*, 28:1120–1124, 2021. doi: 10.1093/jamia/ocab035.

J. S. Ash, M. Berg, and E. Coiera. Some unintended consequences of information technology in health care: the nature of patient care information system-related errors. *Journal of the American Medical Informatics Association*, 11(2):104–112, 2004. doi: 10.1197/jamia.M1471.

J. A. Austin, I. R. Smith, and A. Tariq. The impact of closed-loop electronic medication management on time to first dose: A comparative study between paper and digital hospital environments. *International Journal of Pharmacy Practice*, 26:526–533, 2018. doi: 10.1111/ijpp.12432.

D. W. Bates, D. Levine, A. Syrowatka, M. Kuznetsova, K. J. T. Craig, A. Rui, G. P. Jackson, and K. Rhee. The potential of artificial intelligence to improve patient safety: A scoping review. *NPJ Digital Medicine*, 4:54, 2021. doi: 10.1038/s41746-021-00423-6.

David W. Bates, Gilad J. Kuperman, and Ashish K. Jha. Does the use of computerized provider order entry reduce medication errors? a review of the evidence. *Journal of the American Medical Informatics Association*, 21(4):735–741, 2014. doi: 10.1136/amiajnl-2013-002374.

A. Belle, M. A. Kon, and K. Najarian. Biomedical informatics for computer-aided decision support systems: A survey. *The Scientific World Journal*, 2013(1):769639, 2013a.

Ashwin Belle, Mark A Kon, and Kayvan Najarian. Biomedical informatics for computer-aided decision support systems: A survey. *The Scientific World Journal*, 2013(1):769639, 2013b.

D. M. Berwick, T. W. Nolan, and J. Whittington. The triple aim: Care, health, and cost. *Health Affairs*, 27: 759–769, 2008. doi: 10.1377/hlthaff.27.3.759.

J. K. Bowles, J. Mendoza-Santana, A. F. Vermeulen, T. Webber, and E. Blackledge. *Integrating healthcare data for enhanced citizen-centred care and analytics*. IOS Press, 2020a.

Juliana KF Bowles, Juan Mendoza-Santana, Andreas F Vermeulen, Thais Webber, and Euan Blackledge. Integrating healthcare data for enhanced citizen-centred care and analytics. In *Integrated Citizen Centered Digital Health and Social Care*, pages 17–21. IOS Press, 2020b.

J. Boytim and B. Ulrich. Factors contributing to perioperative medication errors: A systematic literature review. *AORN Journal*, 107:91–107, 2018. doi: 10.1002/aorn.12005.

Bachar F. Chaya, Ricardo Rodriguez Colon, Daniel Boczar, David A. Daar, Hilliard T. Brydges, Erika Thys, Rami S. Kantar, and Pierre B. Saadeh. Perioperative medication management in elective plastic surgery procedures. *Journal of Craniofacial Surgery*, 2023. doi: 10.1097/scs.0000000000009183.

A. Ciapponi, S. E. Fernandez Nievas, M. Seijo, M. B. Rodríguez, V. Vietto, H. A. García-Perdomo, S. Virgilio, A. V. Fajreldines, J. Tost, and C. J. Rose. Reducing medication errors for adults in hospital settings. *Cochrane Database of Systematic Reviews*, 25:CD009985, 2021. doi: 10.1002/14651858.CD009985.pub2.

R. H. Dolin, L. Alschuler, S. Boyer, C. Beebe, F. M. Behlen, P. V. Biron, and A. Shabo. Hl7 clinical document architecture, release 2. *Journal of the American Medical Informatics Association*, 13:30–39, 2006. doi: 10.1197/jamia.M1888.

A. Donabedian. The quality of care. how can it be assessed? *JAMA*, 260:1743–1748, 1988. doi: 10.1001/jama.1988.03410120089033.

European Commission. ehealth action plan 2012-2020: Innovative healthcare for the 21st century. *Official Journal of the European Union*, L 32:1–27, 2016.

Nazanin Falconer, Corey Monaghan, and Centaine L Snoswell. The pharmacist informatician: providing an innovative model of care during the covid-19 crisis. *International Journal of Pharmacy Practice*, 29 (2):152–156, 2021.

M. Fowler. *Refactoring: Improving the Design of Existing Code*. Addison-Wesley, 2nd edition, 2018.

Gianpaolo Franzoso. An effective tool to manage the distribution of medicines and monitor the treatment in hospital pharmacies. *Online Journal of Public Health Informatics*, 6(2):e183, 2014. doi: 10.5210/ojphi.v6i2.5315.

Parvin Ghobadi, Mohammad Gholami, Shirin Hasanvand, Tahereh Toulabi, Nasrolah Moradifar, and Mehdi Birjandi. Effects of a multidisciplinary management program on symptom burden and medication adherence in heart failure patients with comorbidities: A randomized controlled trial. *BMC Nursing*, 2022. doi: 10.1186/s12912-022-01130-7.

T. Greenhalgh, J. Wherton, C. Papoutsi, J. Lynch, G. Hughes, C. A'Court, S. Hinder, N. Fahy, R. Procter, and S. Shaw. Beyond adoption: A new framework for theorizing and evaluating nonadoption, abandonment,

and challenges to the scale-up, spread, and sustainability of health and care technologies. *Journal of Medical Internet Research*, 19:e367, 2017. doi: 10.2196/jmir.8775.

C. E. Hawley, L. K. Triantafylidis, S. C. Phillips, and A. W. Schwartz. Brown bag simulation to improve medication management in older adults. *MedEdPORTAL*, 15:10857, 2019.

M. Hertzum, G. Ellingsen, and Å. Cajander. Implementing large-scale electronic health records: Experiences from implementations of epic in denmark and finland. *International Journal of Medical Informatics*, 167:104868, 2022. doi: 10.1016/j.ijmedinf.2022.104868.

R. J. Holden and B. T. Karsh. The technology acceptance model: Its past and its future in health care. *Journal of Biomedical Informatics*, 43:159–172, 2011. doi: 10.1016/j.jbi.2009.07.002.

A. N. Isaacs, K. Ch'ng, N. Delhiwale, K. Taylor, B. Kent, and A. Raymond. Hospital medication errors: A cross-sectional study. *International Journal for Quality in Health Care*, 33:mzaa136, 2021. doi: 10.1093/intqhc/mzaa136.

Shumaila Javaid, Sherali Zeadally, Hamza Fahim, and Bin He. Medical sensors and their integration in wireless body area networks for pervasive healthcare delivery: A review. *IEEE Sensors Journal*, 22(5): 3860–3877, 2022.

Xiao Ming Jiang. Design and implementation of computer equipment management system based on oracle database. *Applied Mechanics and Materials*, 644-650:3157–3159, 2014. doi: 10.4028/www.scientific.net/AMM.644-650.3157.

S. Kallio, T. Eskola, M. Pohjanoksa-Mäntylä, and M. Airaksinen. Medication risk management in routine dispensing in community pharmacies. *International Journal of Environmental Research and Public Health*, 17(21):8186, 2020. doi: 10.3390/ijerph17218186.

Sonja Kallio, Tiina Eskola, Marja Airaksinen, and Marika Pohjanoksa-Mäntylä. Identifying gaps in community pharmacists' competence in medication risk management in routine dispensing. *Innovations in Pharmacy*, 2021. doi: 10.24926/iip.v12i1.3510.

Alireza Kazemi, Reza Rabiei, Hamid Moghaddasi, and Ghasem Deimazar. Pharmacy information systems in teaching hospitals: A multi-dimensional evaluation study. *Healthcare Informatics Research*, 22(3): 231–237, 2016. doi: 10.4258/hir.2016.22.3.231.

J. Keasberry, I. Scott, C. Sullivan, A. Staib, and R. Ashby. Going digital: A narrative overview of the clinical and organisational impacts of ehealth technologies in hospital practice. *Australian Health Review*, 41: 646–664, 2017. doi: 10.1071/AH16233.

Johannes Keller, Adrian Lindenmeyer, Malte Blattmann, Jan Gaebel, Daniel Schneider, Thomas Neumuth, and Stefan Franke. Using digital twins to support multiple stages of the patient journey. In *dHealth 2023*, pages 227–232. IOS Press, 2023.

L. T. Kohn, J. M. Corrigan, and M. S. Donaldson. *To Err is Human: Building a Safer Health System*. National Academy Press, Washington, DC, 2000.

James R. Lewis. The system usability scale: Past, present, and future. *International Journal of Human–Computer Interaction*, 34(7):577–590, 2018. doi: 10.1080/10447318.2018.1455307.

S. C. Lin, A. K. Jha, and J. Adler-Milstein. Electronic health records associated with lower hospital mortality after systems have time to mature. *Health Affairs*, 37:1128–1135, 2018. doi: 10.1377/hlthaff.2017.1658.

Naldy Parodi López, Staffan Svensson, and Sven Wallerstedt. Association between recorded medication reviews in primary care and adequate drug treatment management – a cross-sectional study. *Scandinavian Journal of Primary Health Care*, 2021. doi: 10.1080/02813432.2021.1973239.

José Machado, Carla Rodrigues, Regina Sousa, and Luis Mendes Gomes. Drug–drug interaction extraction-based system: An natural language processing approach. *Expert Systems*, page e13303, 2023.

K. D. Mandl, D. Gottlieb, and A. M. Ellis. Transforming healthcare with fhir: A decade of change. *Journal of Medical Internet Research*, 22(12):e21546, 2020. doi: 10.2196/21546.

E. Manias, G. Street, J. K. Lowe, M. Low, K. Gray, and M. Botti. Associations of person-related, environment-related and communication-related factors on medication errors in public and private hospitals: A retrospective clinical audit. *BMC Health Services Research*, 21:1025, 2021. doi: 10.1186/s12913-021-07033-8.

R. C. Martin. *Clean Architecture: A Craftsman's Guide to Software Structure and Design*. Prentice Hall, Upper Saddle River, NJ, 2017.

C. May and T. Finch. Implementing, embedding, and integrating practices: An outline of normalization process theory. *Sociology*, 47(2):535–554, 2013. doi: 10.1177/0038038509103208.

J. D. McGreevey, C. P. Mallozzi, R. M. Perkins, E. Shelov, and R. Schreiber. Reducing alert burden in electronic health records: State of the art recommendations from four health systems. *Applied Clinical Informatics*, 11:1–12, 2020. doi: 10.1055/s-0039-3402715.

S. Misra, S. Jeon, S. Lee, J. Kim, and S. Kim. Machine learning in healthcare: A systematic review of applications and challenges. *Journal of Medical Internet Research*, 25:e13477, 2023. doi: 10.2196/13477.

J. Moss and E. S. Berner. Evaluating clinical decision support tools for medication administration safety in a simulated environment. *International Journal of Medical Informatics*, 84:308–318, 2015. doi: 10.1016/j.ijmedinf.2015.01.018.

A. Mulac, K. Taxis, E. Hagesaether, and A. G. Granas. Severe and fatal medication errors in hospitals: Findings from the norwegian incident reporting system. *European Journal of Hospital Pharmacy*, 28: e56–e61, 2020. doi: 10.1136/ejhpharm-2020-002298.

S. Newman. *Building Microservices: Designing Fine-Grained Systems*. O'Reilly Media, 2nd edition, 2021.

Jakob Nielsen. Usability 101: Introduction to usability. *Nielsen Norman Group*, 2012. URL https://www.nngroup.com/articles/usability-101-introduction-to-usability/.

L. Nkenyereye and J. W. Jang. Performance evaluation of server-side javascript for healthcare hub server in remote healthcare monitoring system. *Procedia Computer Science*, 98:382–387, 2016a.

Lionel Nkenyereye and Jong-Wook Jang. Performance evaluation of server-side javascript for healthcare hub server in remote healthcare monitoring system. *Procedia Computer Science*, 98:382–387, 2016b.

E. M. Rogers. *Diffusion of Innovations*. Free Press, 5th edition, 2003.

R. Rozenblum, R. Rodriguez-Monguio, L. A. Volk, K. J. Forsythe, S. Myers, M. McGurrin, R. Giannini, G. D. Schiff, and D. W. Bates. Using machine learning to predict medication errors in an inpatient setting. *Journal of the American Medical Informatics Association*, 27:801–807, 2020. doi: 10.1093/jamia/ocaa017.

Cynthia L. Russell. A descriptive, correlational study of perceptions of adult kidney transplant recipients and those waiting for a kidney transplant about managing their medications during a pandemic. *Progress in Transplantation*, 2023. doi: 10.1177/15269248231212906.

Susan B. Shermock, Kenneth M. Shermock, and Lotta L. Schepel. Closed-loop medication management with an electronic health record system in u.s. and finnish hospitals. *International Journal of Environmental Research and Public Health*, 20(17):6680, 2023. doi: 10.3390/ijerph20176680.

Cedomir Stanojevic, Casey C Bennett, Selma Sabanovic, Sawyer Collins, Kenna Baugus Henkel, Zachary Henkel, and Jennifer A Piatt. Conceptualizing socially-assistive robots as a digital therapeutic tool in healthcare. *Frontiers in digital health*, 5:1208350, 2023.

Carina Tukukino, Naldy Parodi López, Staffan Svensson, and Sven Wallerstedt. Drug interaction alerts in older primary care patients, and related medically justified actions. *European Journal of Clinical Pharmacology*, 2022. doi: 10.1007/s00228-022-03292-4.

M. R. Vaghasiya, J. Penm, K. K. Y. Kuan, N. Gunja, Y. Liu, E. D. Kim, N. Petrina, and S. Poon. Implementation of an electronic medication management system in a large tertiary hospital: A case of qualitative inquiry. *BMC Medical Informatics and Decision Making*, 21:226, 2021. doi: 10.1186/s12911-021-01584-w.

Milan R. Vaghasiya, Simon K. Poon, Naren Gunja, and Jonathan Penm. The impact of an electronic medication management system on medication deviations on admission and discharge from hospital. *International Journal of Environmental Research and Public Health*, 20(3):1879, 2023. doi: 10.3390/ijerph20031879.

V. Venkatesh, M. G. Morris, G. B. Davis, and F. D. Davis. User acceptance of information technology: Toward a unified view. *MIS Quarterly*, 27:425–478, 2003. doi: 10.2307/30036540.

World Health Organization. Medication without harm—who global patient safety challenge on medication safety. WHO, Geneva, Switzerland, 2017. URL https://www.who.int/publications/i/item/WHO-HIS-SDS-2017.6.

World Health Organization. Medication safety in transitions of care. WHO, 2022. URL https://www.who.int/publications/i/item/WHO-UHC-SDS-2019.9.

J. Zhao, Y. Zhang, D. C. Schwebel, and M. Zhu. Artificial intelligence in healthcare: A comprehensive review. *Nature Medicine*, 27:727–735, 2021. doi: 10.1038/s41591-021-01273-1.