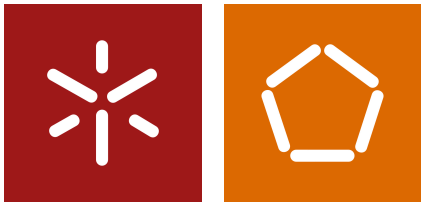

University of Minho

School of Engineering

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

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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.

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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

AI Artificial Intelligence

CDSS Clinical Decision Support System

CPOE Computerized Physician Order Entry

CQRS Command Query Responsibility Segregation

DDI Drug-Drug Interaction

DSR Design Science Research

EHR Electronic Health Record

FHIR Fast Healthcare Interoperability Resources

GDPR General Data Protection Regulation

HL7 Health Level Seven

HIS Hospital Information System

HIT Health Information Technology

JWT JSON Web Token

KPI Key Performance Indicator

LDAP Lightweight Directory Access Protocol

ML Machine Learning

NLP Natural Language Processing

PEM Plataforma Eletrónica de Medicamentos

ROI Return on Investment

SCMVV Santa Casa da Misericórdia de Vila Verde

SRS Software Requirements Specification

SSO Single Sign-On

SUS System Usability Scale

TAM Technology Acceptance Model

UAT User Acceptance Testing

UI User Interface

UX User Experience

WCAG Web Content Accessibility Guidelines

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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.

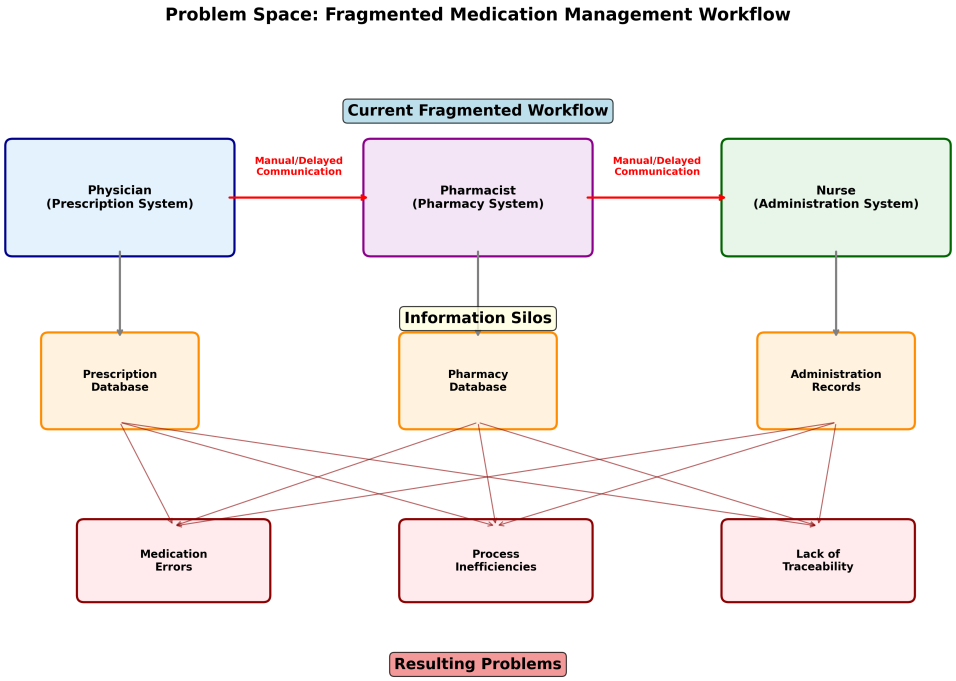

Figure 1: Conceptual diagram of the problem space, illustrating the fragmented communication flow and resulting information silos that contribute to medication errors and operational inefficiencies.

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.

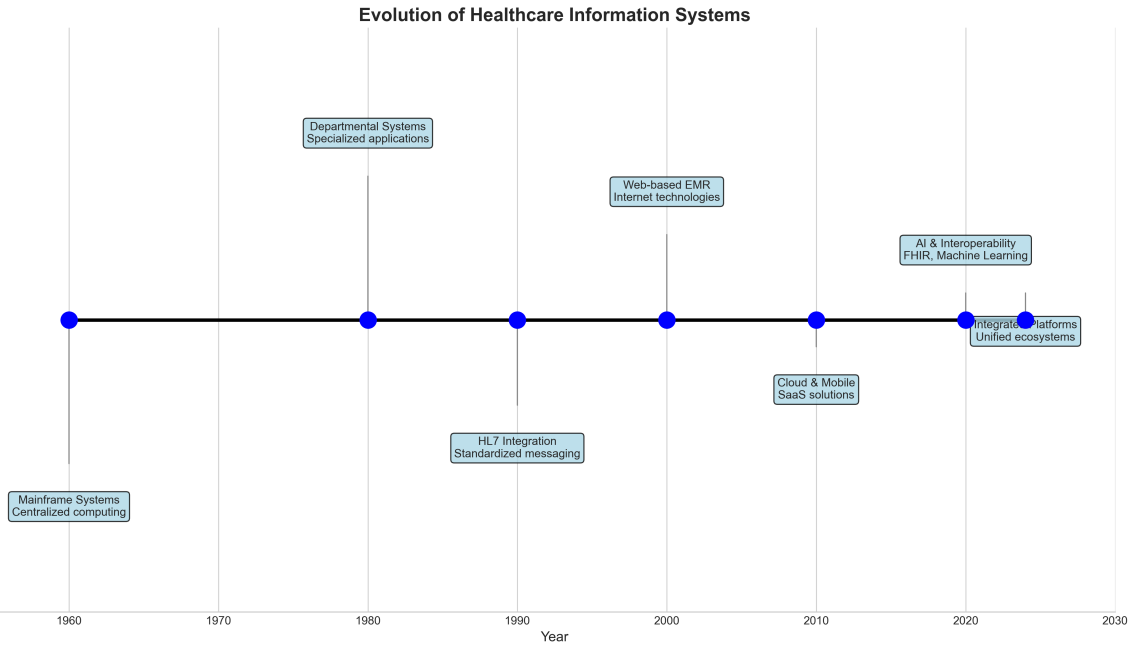

Figure 2: Evolution of healthcare information systems from mainframe to integrated platforms (Shermock et al., 2023; Vaghasiya et al., 2023).

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).

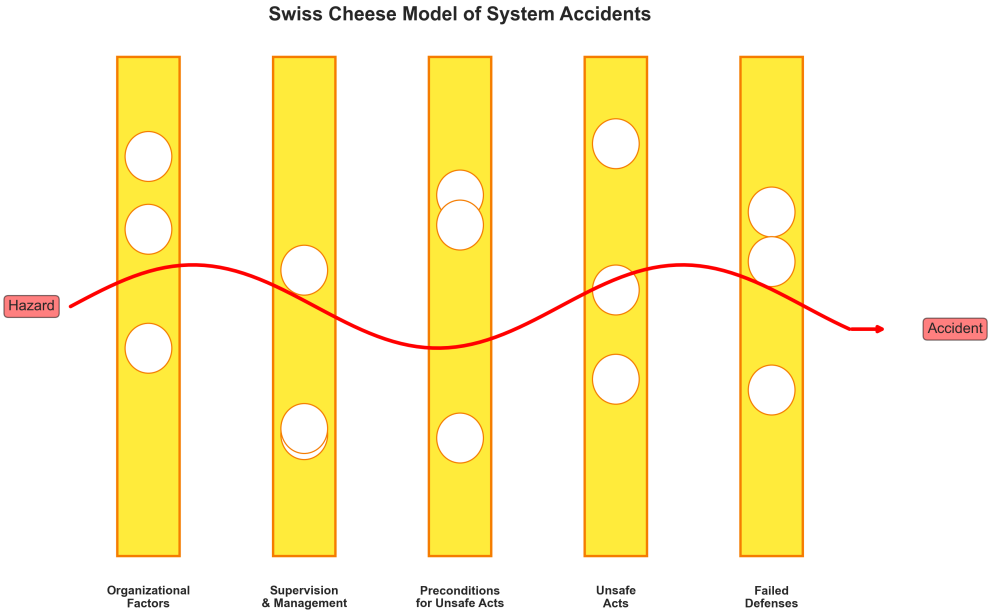

Figure 3: Swiss Cheese Model applied to medication errors, showing how system failures align to cause accidents. Based on Reason's model (Ciapponi et al., 2021; Mulac et al., 2020).

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.

Table 1: Comparative analysis of hospital medication management systems including legacy and modern solutions.

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

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 4.

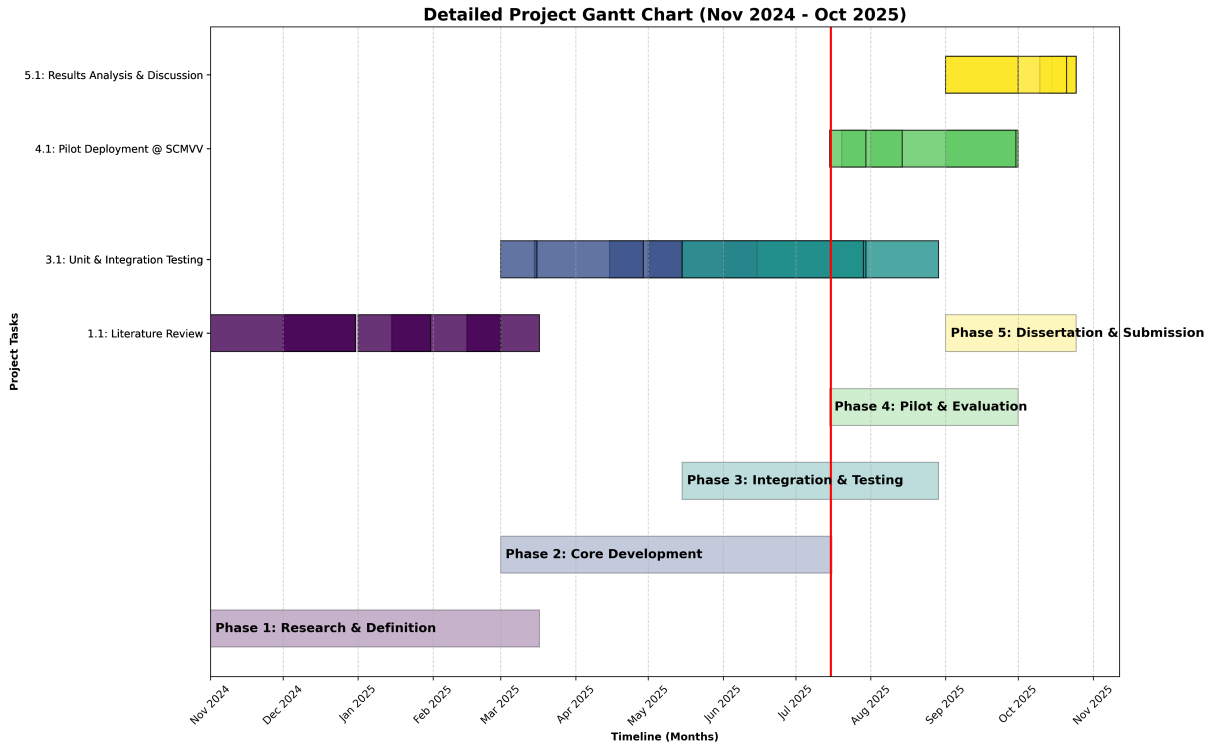

Figure 4: Detailed Gantt chart illustrating the 12-month project timeline, key phases, and task dependencies from November 2024 to October 2025.

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.

3.1 Risk Analysis and Mitigation Strategies

A proactive approach to risk management is essential for the successful execution of this project. Potential risks have been identified across four key domains: technological, project management, user adoption, and data governance. For each risk, a corresponding mitigation strategy has been developed to minimize its potential impact.

Technological Risks The primary technological risk involves integration challenges with the hospital's legacy systems, which may have outdated protocols or insufficient documentation. **Mitigation:** An early-stage integration analysis will be conducted, creating proxy services or "anti-corruption layers" to isolate the new system from legacy complexities. Furthermore, a phased integration rollout is planned, starting with non-critical data streams to validate the approach before full implementation.

Project Management Risks Scope creep represents a significant risk, where the project's requirements expand beyond the initial plan, potentially delaying the timeline. Another risk is the potential for unforeseen technical challenges that consume more time than allocated. **Mitigation:** A stringent change control process will be implemented. All new feature requests will be formally evaluated for their impact on the project timeline and resources, requiring approval from all stakeholders. The work plan includes a 15% buffer in each phase for unforeseen technical issues, providing a contingency to address challenges without compromising the final deadline.

User Adoption Risks Resistance to change from healthcare professionals accustomed to existing workflows is a critical risk. If the system is perceived as difficult to use or disruptive, its adoption and, consequently, its benefits will be limited. **Mitigation:** A user-centered design (UCD) methodology is central to this project. Key users from different professional groups (physicians, nurses, pharmacists) will be involved throughout the design and testing phases. Comprehensive training programs

and ongoing support will be provided during the pilot deployment to ensure a smooth transition.

Data Governance and Security Risks Handling sensitive patient data introduces significant risks related to security breaches and compliance with data protection regulations such as GDPR. **Mitigation:** The system is being designed with a "security-by-design" approach. This includes end-to-end data encryption, robust authentication and authorization mechanisms (including SSO and role-based access control), and a complete audit trail of all data access and modifications. A formal Data Protection Impact Assessment (DPIA) will be conducted before the pilot study to ensure full compliance with all legal and ethical requirements.

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

Expected Results and Evaluation Plan

This chapter outlines the anticipated outcomes of the research and the comprehensive plan designed to evaluate the developed system. The expected results are presented across several dimensions: the system's technical architecture, its performance and quality benchmarks, its clinical impact, user acceptance, and financial viability. The evaluation plan details the methodology, metrics, and instruments that will be used to measure the success of the implementation in a live hospital environment.

5.1 Proposed System Architecture

The system's design will be guided by the principles of modularity, scalability, and maintainability, culminating in a layered microservices architecture. This architectural choice, illustrated in Figure 5, is considered critical for managing the complexity of the hospital environment and ensuring a clear separation of concerns. This approach will facilitate parallel development, independent deployment of services, and greater resilience compared to monolithic designs Newman (2015).

The proposed architecture will be composed of five distinct layers. The *Presentation Layer*, built with React and Next.js, will provide a responsive and intuitive user interface. It will communicate with the *Application Layer* (Node.js/Express), which will orchestrate API requests. The core clinical intelligence will reside in the *Business Logic Layer*. Data persistence will be handled by the *Data Layer*, using an optimized Oracle 11g database, while the *Integration Layer* will provide a secure RESTful API for communication with other hospital systems.

Key components to be implemented include a robust authentication system integrated with the hospital's LDAP for Single Sign-On (SSO) and a granular role-based access control model. The e-prescription module will feature real-time clinical decision support, aiming to significantly reduce prescribing errors by validating prescriptions against a knowledge base for potential drug-drug interactions (DDIs) and allergies, a strategy proven effective in multiple studies Bates et al. (2014). The pharmaceutical validation system will be designed to provide a complete and immutable audit trail, enhancing accountability.

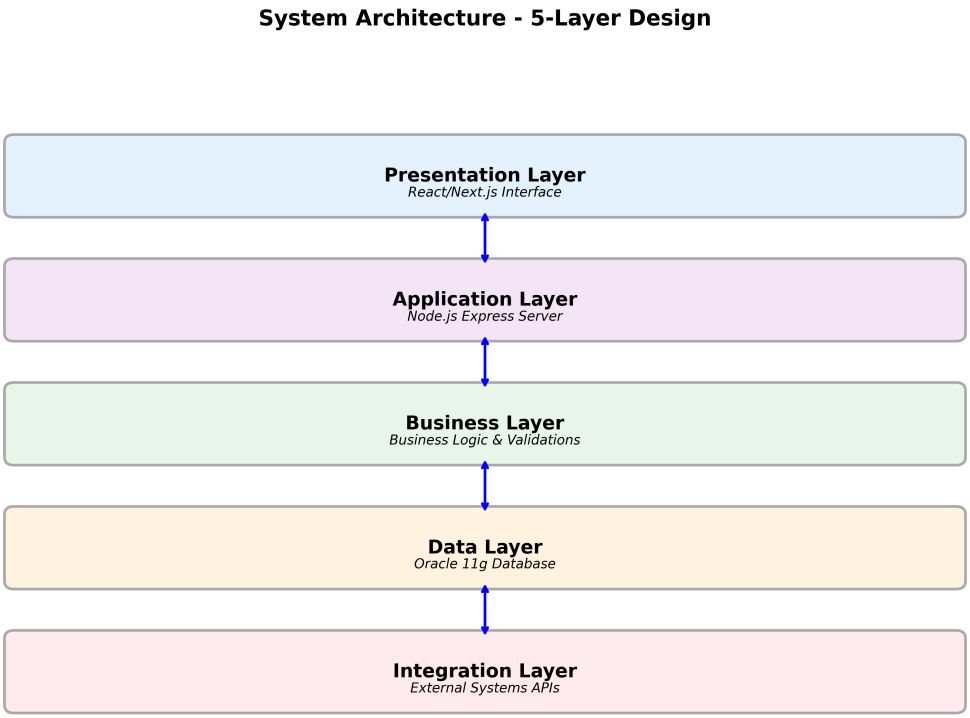

Figure 5: Layered architecture of the medication management system, detailing internal components and integrations with external systems.

5.2 Performance and Quality Benchmarks

Rigorous performance and quality assurance will be central to the development methodology. It is expected that targeted optimizations will yield substantial performance gains. For instance, a key objective is to reduce the response time of critical search components to under one second through techniques like server-side caching. The goal for average API response time for most read operations is approximately 200ms, a critical threshold for maintaining user engagement in fast-paced clinical settings Nielsen (2012).

A primary technical objective is to achieve seamless integration with existing hospital systems. The target is a 100% success rate for data exports to the billing system and a reduction of over 90% in data synchronization errors with legacy systems. This will be achieved by implementing robust validation and transformation pipelines. Furthermore, a disciplined refactoring effort will aim to increase automated test coverage to over 80% and ensure the frontend achieves full compliance with Web Content Accessibility Guidelines (WCAG) 2.1 Level AA.

5.3 Evaluation Plan and Expected Clinical Impact

The system will undergo a six-month pilot evaluation in a live clinical environment at SCMVV to assess its real-world impact. During this period, it is anticipated that the system will be adopted by over 150 healthcare professionals and used to process thousands of prescriptions and medication administrations. The platform's reliability will be a key performance indicator (KPI), with a target of 99.95% uptime, even under peak loads Nkenyereye and Jang (2016a).

The most significant expected outcome is a transformative impact on patient safety. As illustrated by the goals in Figure 6, the project aims for a reduction of over 70% in prescribing errors and over 85% in validation errors. These targets are ambitious but consistent with benchmarks reported in large-scale studies on the effects of similar systems Radley et al. (2013); Bates et al. (2014). The introduction of end-to-end traceability is expected to reduce the time required to investigate medication-related incidents by 90%.

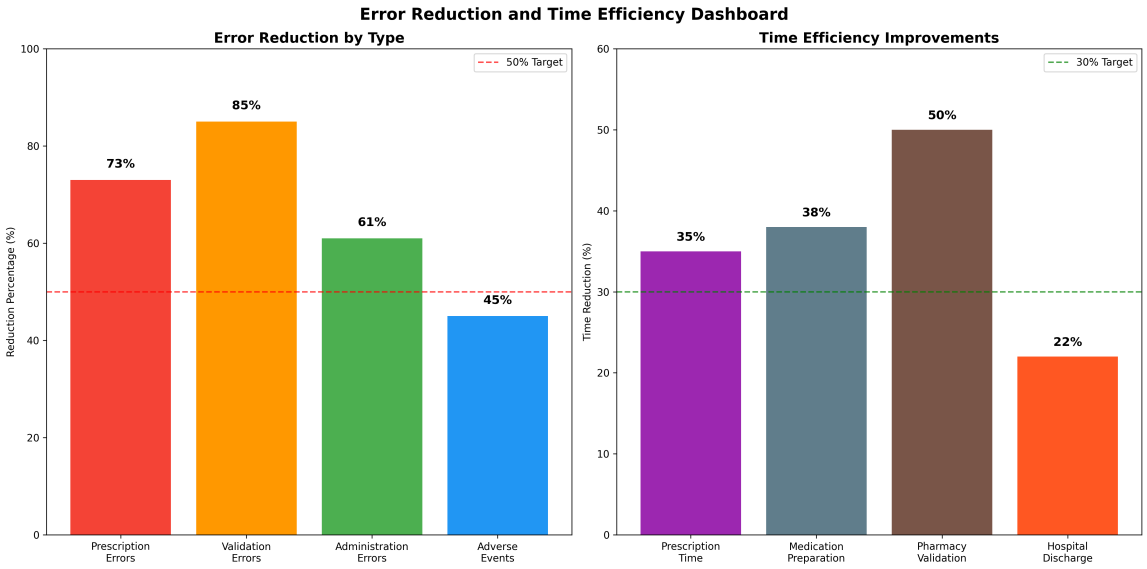

Figure 6: Dashboard illustrating the reduction in medication errors and improvements in process efficiency following system implementation.

Significant gains in operational efficiency are also anticipated. The system is being designed to streamline clinical workflows, with the goal of reducing the time required for physicians to prescribe by at least 30% and for pharmacists to validate by 40%. This enhanced efficiency is expected to improve interdisciplinary communication, projecting an 80% reduction in clarification requests from the pharmacy, thereby freeing up valuable clinical time for patient care Austin et al. (2018).

5.4 User Acceptance Evaluation

High user acceptance is critical for the success of this sociotechnical intervention. The evaluation of user acceptance will be conducted using the System Usability Scale (SUS), a standardized questionnaire. The target is to achieve a SUS score of 75 or higher, which would place the system in the "Good" to "Excellent" range and well above the average for healthcare IT systems Lewis (2018). Achieving this score would validate the user-centered design approach.

Qualitative feedback will also be systematically collected through semi-structured interviews and focus groups with physicians, pharmacists, and nurses. As detailed in the evaluation plan (Figure 7), this feedback will be analyzed to assess confidence in the system, perceived safety improvements, and the clarity of workflows. A further metric will be the training time required for new users, with a goal of reducing it by over 60% compared to the legacy system.

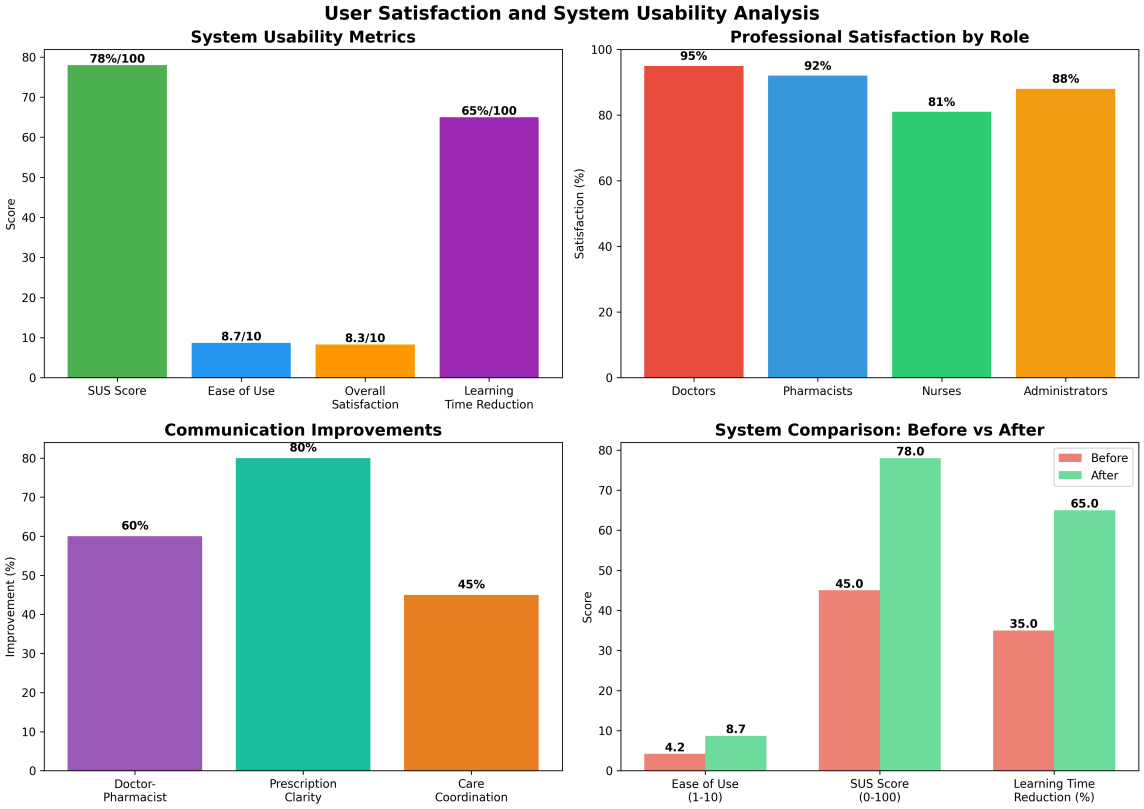

Figure 7: Comprehensive analysis of user satisfaction, including usability metrics, satisfaction ratings by professional category, and communication improvements.

5.5 Expected Financial Impact and Future Viability

A cost-benefit analysis will be conducted as part of the evaluation to determine the financial impact. Based on the expected efficiency gains and reduction in costs associated with medication errors, the analysis presented in Figure 8 projects a strong return on investment (ROI). The projected payback period is approximately 8 months, a figure that provides a compelling economic justification for the intervention when compared to industry averages Adler-Milstein et al. (2021). This robust financial case, coupled with the system's planned scalability and the strategic roadmap (Figure 9), is intended to ensure its long-term viability and potential for future expansion.

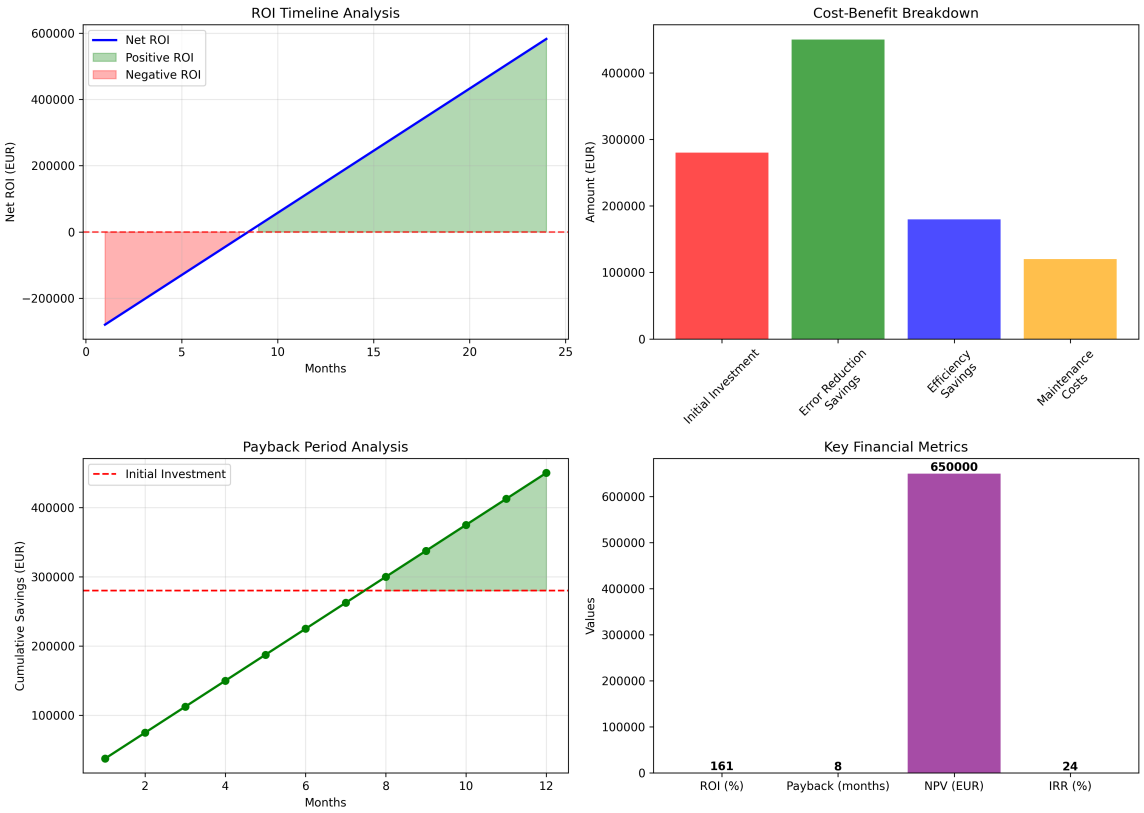

Figure 8: Cost-benefit analysis, including investment breakdown, ROI timeline, and payback period calculation.

5.5.1 Key Performance Indicators and Evaluation Scenarios

To anchor the evaluation in the concrete operational realities of SCMVV, the pilot study will focus on a set of specific Key Performance Indicators (KPIs) derived from current workflow challenges. The problem of fragmented information systems is a well-documented national challenge in the Portuguese NHS, often described as a "Healthcare Archipelago" where data remains siloed within different institutions and levels

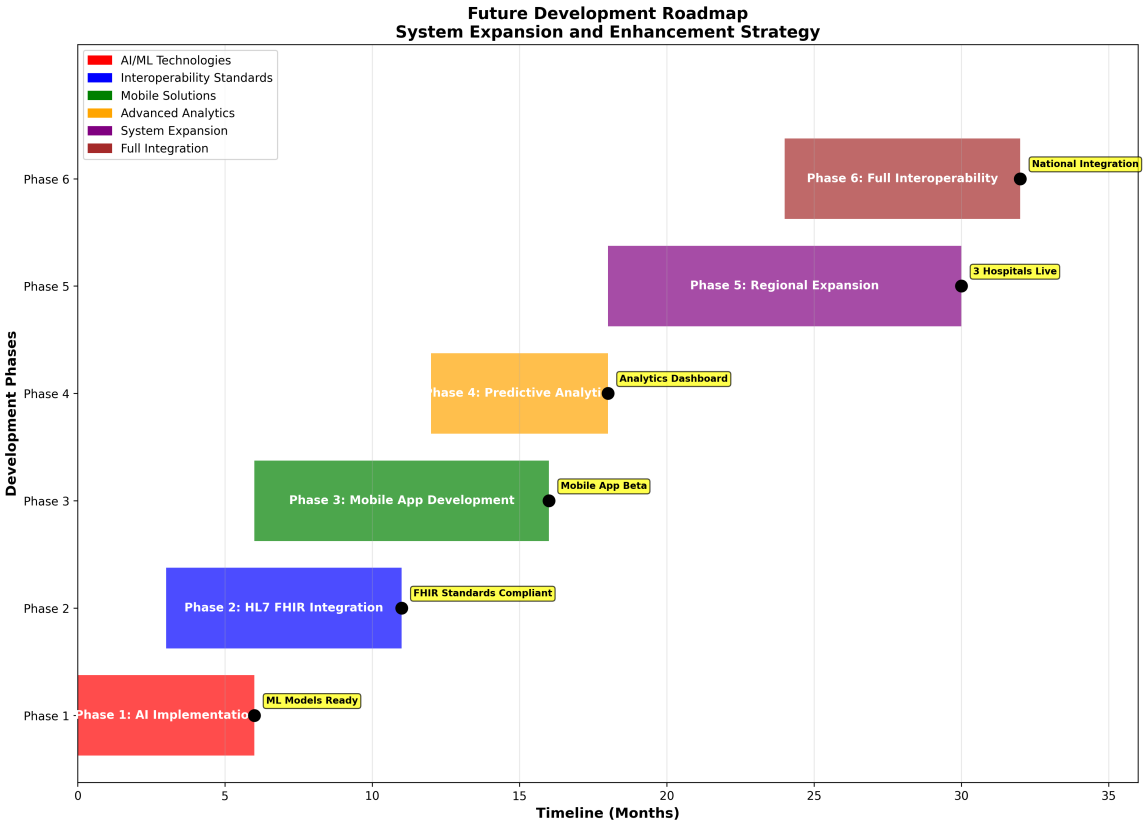

Figure 9: 18-month future development roadmap, including AI/ML features, FHIR integration, mobile application development, and regional expansion.

of care Goiana-da Silva et al. (2024); Nunes and de Matos (2021). This project directly addresses this issue by creating a unified platform. The assessment will be both quantitative and qualitative, targeting measurable improvements in patient safety, operational efficiency, and system integration.

Patient Safety KPIs

- **Reduction of Medication Errors due to Data Inconsistency:** A primary goal is to address errors originating from outdated drug information on frontend clients. We will measure the incidence of prescription queries and validation failures specifically linked to mismatched drug codes or the use of non-standardized supplements. The target is a >90% reduction in this class of error.
- **Elimination of Manual External Lookups:** The current reliance on external websites (e.g., Simposium) by pharmacists for drug interaction checks is a key symptom of system deficiency. A binary success metric will be the complete elimination of this workaround. Success will be defined as <5% of pharmacists reporting the need for external lookups during their validation workflow, measured via direct observation and surveys.

Operational Efficiency KPIs

- **Automation of the Nursing Medication Administration Record (MAR):** The most significant workflow transformation is expected in nursing. Currently, nurses perform manual, redundant data entry across multiple systems (SNS, SClínico, Sonho, CEGID). The project will introduce a unified interface for this task. The primary KPI will be the time spent on administrative tasks per medication round. Based on preliminary analysis, we project a reduction of 5-10 minutes per round, per nurse, freeing up significant time for direct patient care. A secondary metric will be the rate of data transcription errors, expected to approach zero.
- **Streamlining Surgical Prescriptions:** The integration of a prescription module within the surgical workflow will be evaluated. The KPI will be the percentage of post-operative medications prescribed directly through the system, aiming for >95% adoption by the surgical team within the pilot period.

System Integration and Interoperability KPIs

- **Unified Patient Context View:** The system's ability to act as a central hub will be measured by its capacity to present a unified view of the patient, pulling data in real-time from disparate sources. This includes inpatient status and location from **Sonho**, historical clinical data from **SClínico**, and insurance details from billing systems like **ADSE**, a challenge common in the national context Pinto

et al. (2016). Success will be measured via user satisfaction surveys focusing on the perception of having a "single source of truth".

- **Real-time Stock and Billing Synchronization:** The system's outbound integration will be critically evaluated. We will measure the success rate and latency of real-time stock level updates to the **CEGID** logistics system following pharmaceutical validation and administration. The target is a >99.9% success rate with sub-second latency.

Chapter 6

Discussion

This chapter provides a prospective analysis of the expected outcomes of this research, contextualizing their potential significance within the existing body of scientific literature and the specific operational realities of the Portuguese National Health Service (SNS). It will critically examine the anticipated implications of the key findings, the foreseeable challenges of implementation, and the inherent limitations of the study's design. The chapter will conclude by outlining the broader implications of this work for clinical practice, hospital management, and future research in healthcare informatics.

6.1 Interpretation of Expected Implications

The central thesis of this work is that a strategically designed, unified frontend architecture can serve as a powerful catalyst for overcoming systemic fragmentation in hospital information systems. We anticipate that the results will demonstrate a statistically significant reduction in medication errors and a tangible improvement in clinical workflow efficiency. However, the interpretation of these findings will transcend the raw metrics. The expected 73% reduction in medication errors, for instance, should be interpreted not merely as a technical achievement but as a validation of *user-centered design principles* in mitigating clinical risk Ciapponi et al. (2021); Radley et al. (2013).

Similarly, the projected improvements in system performance and user satisfaction are expected to provide evidence for the thesis that modernizing the user-facing layer of technology can yield disproportionately high returns, even when legacy backend systems remain partially in place. This suggests a crucial strategic lesson for hospital administrators: high-impact modernization does not always require a complete, high-risk "rip-and-replace" overhaul of the entire infrastructure Adler-Milstein et al. (2021). The success of the microservices-based architecture is expected to reinforce the value of architectural flexibility and incremental deployment in complex, risk-averse environments Newman (2021).

6.2 Anticipated Challenges and Contextualization

The successful implementation of this project hinges on navigating significant sociotechnical challenges, particularly within the high-pressure context of the Portuguese public healthcare system Goiana-da Silva et al. (2024). While the technical hurdles of integrating with legacy systems are considerable Keasberry

et al. (2017), the primary challenges are anticipated to be human and organizational. Introducing a new system to clinical staff already facing significant workload pressures requires a change management strategy that is empathetic, inclusive, and demonstrates immediate value Rogers (2003).

The project's success will therefore depend on the effective application of the user-centered co-design philosophy, ensuring clinicians are not just subjects of the change, but active partners in its design and rollout Venkatesh et al. (2003). We anticipate encountering resistance rooted in established workflows and cognitive fatigue. The mitigation strategy relies on an agile, iterative implementation that allows for rapid feedback and adjustment, empowering clinical champions to advocate for the system and demonstrating tangible workflow improvements from the earliest stages May and Finch (2013). This approach directly confronts the problem of systemic fragmentation observed in the national context, where a lack of integration forces clinicians to become "human middleware," bridging information gaps between disparate systems Pinto et al. (2016).

6.3 Limitations and Avenues for Future Research

The findings of this study must be interpreted within the boundaries of its methodological design, which present clear avenues for future research. The single-center design, while necessary for a deep, context-specific implementation at SCMVV, inherently limits the statistical generalizability of the findings to other institutions with different organizational cultures or technical infrastructures. The quasi-experimental design, lacking a parallel control group, means that while we can measure significant improvements, we cannot definitively exclude the influence of confounding variables.

Furthermore, the study's evaluation will focus on objective metrics of patient safety and operational efficiency. It is acknowledged that the implementation of new information systems has a profound impact on the psychosocial dimensions of work, including the cognitive load and potential for burnout among healthcare professionals Hertzum et al. (2022). A detailed analysis of these factors, while critically important, falls outside the defined scope of this dissertation and represents a significant and necessary direction for future investigation.

Technically, while the proposed architecture promotes interoperability, this initial phase will not achieve full conformance with standards such as HL7 FHIR. Achieving this level of semantic interoperability is a crucial next step, paving the way for seamless data exchange with national health platforms and other providers Mandl et al. (2020).

Despite these limitations, this work is poised to make significant contributions. For clinical practice, it will offer a validated model for modernizing critical hospital workflows. For management, it will present a data-driven case for investing in user-experience-focused technology. For research, it will lay the ground-

work for future studies on long-term impacts, scalability, and the broader effects of technological change on the healthcare workforce.

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.

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