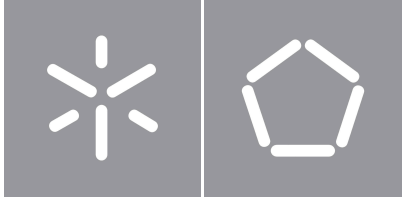
University of Minho
School of Engineering

Diogo André da Silva Esteves

Optimization and Standardization of Medication Management Processes in Hospital Environments

august 2025



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Optimization and Standardization of Medication Management Processes in Hospital Environments

Master's Dissertation in Bioinformatics Engineering

Dissertation supervised by

Prof. Dr. José Manuel Ferreira Machado
Prof. Dr. Ana Regina Coelho de Sousa

august 2025

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To everyone, my sincerest thanks.

Statement of Integrity

I hereby declare having conducted this academic work with integrity.

I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

University of Minho, Braga, august 2025

Diogo André da Silva Esteves

Resumo

A fragmentação dos sistemas de informação no Serviço Nacional de Saúde português representa um desafio sistémico à segurança do doente e à eficiência operacional, particularmente no ciclo do medicamento. Este projeto de dissertação propõe-se a endereçar este problema no contexto da Santa Casa da Misericórdia de Vila Verde (SCMVV) através do desenho, desenvolvimento e avaliação de uma plataforma de software centralizada. O objetivo é unificar os fluxos de trabalho clínico-farmacêuticos, atualmente dispersos por múltiplos sistemas legados, numa única interface de utilizador moderna e coesa.

Adotando uma metodologia de *Design Science Research* (DSR), o projeto irá criar um artefacto tecnológico — um sistema web com uma arquitetura de microsserviços (Node.js) e um frontend reativo (TypeScript/React) — concebido para se integrar com a infraestrutura existente. A avaliação do sistema será focada em indicadores de desempenho chave (KPIs) específicos, antecipando-se uma redução significativa dos erros de medicação e um aumento da eficiência dos processos para enfermeiros e farmacêuticos. A contribuição principal deste trabalho será a validação de um modelo de modernização sociotécnica que, se bem-sucedido, poderá servir de referência para outras unidades de saúde que enfrentam desafios de fragmentação semelhantes.

Palavras-chave: Sistemas de Informação em Saúde, Segurança do Doente, Gestão da Medicação, Design Science Research, Unificação de Sistemas, Interoperabilidade Clínica.

Abstract

The fragmentation of information systems within the Portuguese National Health Service constitutes a systemic challenge to patient safety and operational efficiency, particularly in the medication management lifecycle. This dissertation project aims to address this problem in the context of the Santa Casa da Misericórdia de Vila Verde (SCMVV) by designing, developing, and evaluating a centralized software platform. The primary objective is to unify the clinical-pharmaceutical workflows, currently fragmented across multiple legacy systems, into a single, modern, and cohesive user interface.

Adopting a *Design Science Research* (DSR) methodology, the project will create a technological artifact—a web-based system featuring a microservices architecture (Node.js) and a reactive frontend (TypeScript/React)—designed to integrate with the existing infrastructure. The system's evaluation will focus on specific Key Performance Indicators (KPIs), with the anticipation of achieving a significant reduction in medication errors and an increase in process efficiency for nurses and pharmacists. The main contribution of this work will be the validation of a sociotechnical modernization model that, if successful, could serve as a reference for other healthcare institutions facing similar fragmentation challenges.

Keywords: Health Information Systems,Patient Safety,Medication Management,Design Science Research,System Unification,Clinical Interoperability.

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Acronyms

AIDA-PCE Aplicação Integrada para a Área da Saúde - Prescrição, Codificação e Executável.

API Application Programming Interface.

CDSS Clinical Decision Support System.

DDI Drug-Drug Interaction.

DSR Design Science Research.

HIT Health Information Technology.

JWT JSON Web Token.

PEM Prescrição Eletrónica Médica.

SCMVV Santa Casa da Misericórdia de Vila Verde.

SNS Serviço Nacional de Saúde.

SPMS Serviços Partilhados do Ministério da Saúde.

SSO Single Sign-On.

UI User Interface.

WCAG Web Content Accessibility Guidelines.

Part I

Introductory material

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 (**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 (**Santa Casa da Misericórdia de Vila Verde (SCMVV)**) serves as a representative case study for these systemic challenges. Its core operations rely on the **Aplicação Integrada para a Área da Saúde - Prescrição, Codificação e Executável (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 Bowles et al.

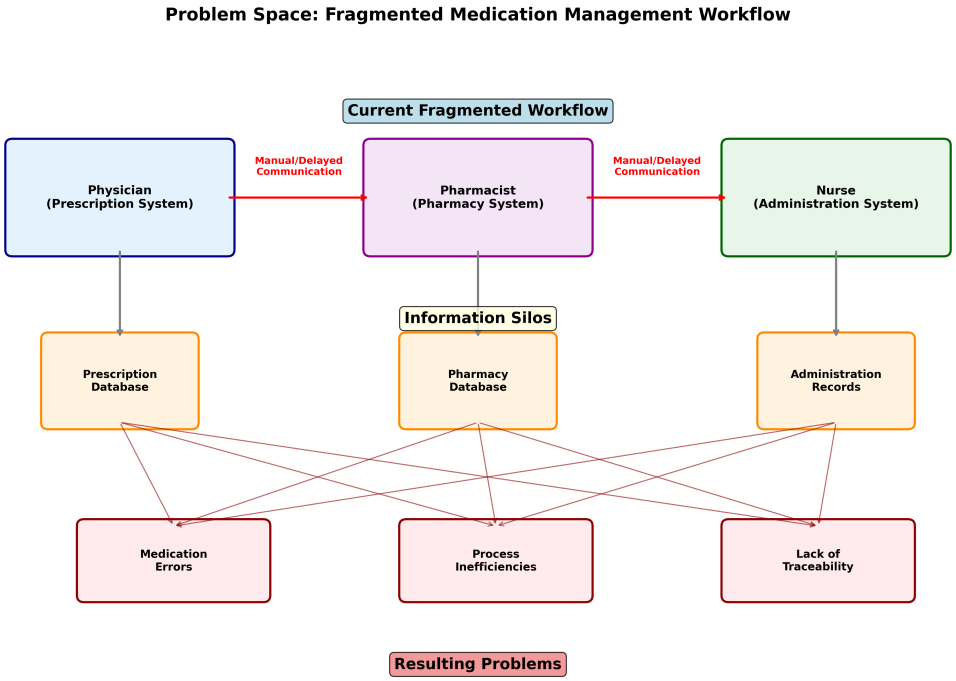

Figure 1: Conceptual diagram of the problem space, illustrating the fragmented communication flow and resulting information silos that contribute to medication errors and operational inefficiencies.

(2020); Moss and Berner (2015). 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.

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); European Commission (2016); Mandl et al. (2020);

Misra et al. (2023).

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, including point-of-care administration (eMAR/BCMA) and process standardization in healthcare (Sections 2.2.3 and 2.2.4), as well as the national context (Section 2.2.6). 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 details the Expected Results and Evaluation Plan. Chapter 6 presents Results obtained to date. Chapter 7 offers a Discussion of these results, contextualizing them within the broader literature. Finally, Chapter 8 provides the Conclusion and Future Work, summarizing the contributions and proposing directions ahead.

1.3 Current Context at SCMVV

To address identified gaps in the contextualization of the case study, this section documents the current medication-management processes and supporting information systems at the Santa Casa da Misericórdia de Vila Verde (**SCMVV**). The intent is to provide a concrete baseline that motivates the proposed solution and frames subsequent evaluation.

- Systems in use and their roles (e.g., **AIDA-PCE** /AIDA-PCE; possible interactions with hospital HIS such as SONHO; national platforms such as **Prescrição Eletrónica Médica (PEM)**), within the scope of medication management.
- End-to-end workflow as practiced today: physician prescription, pharmaceutical validation, stock-/dispensing, and nursing administration, highlighting where manual steps or data re-entry occur.
- Known integration gaps and failure points affecting continuity of care (e.g., absence of real-time decision support or cross-module synchronization).
- Baseline indicators to be captured where available (e.g., error types, volumes of movements for controlled substances, turnaround times), to support before/after reasoning.

1.4 As-is System Architecture (SCMVV)

This section outlines a high-level description of the current (as-is) technical architecture supporting medication management at **SCMVV**, to contrast later with the target architecture. The description will enumerate

principal modules, databases, interfaces, and data flows relevant to prescription, validation, dispensing, and administration, and will explicitly indicate where interfaces or interoperability are absent or manual.

1.5 Current Medication Process Organization at SCMVV

This section documents the organizational perspective of the medication process at **SCMVV**, complementing the technical as-is view. It focuses on roles, handoffs, and standard operating procedures as practiced today, highlighting opportunities for standardization.

- Roles and responsibilities across disciplines: prescribing physicians, hospital pharmacists (validation and stock management), and nursing staff (administration and recording).
- Artefacts (main actual artefact is a legacy artefact in a vb.net project (AIDA-PCE)) and records in use (systems and/or paper forms) at each stage, and where transcriptions or verbal confirmations occur.
- Typical handoffs between departments, including triggers (e.g., a prescription becomes available for validation) and feedback loops.
- Known variability across wards/services and its impact on consistency and safety.
- Pointers to figures/diagrams: process flow diagram of the current cycle; swimlane diagram of cross-role interactions; inventory of current forms/screens.

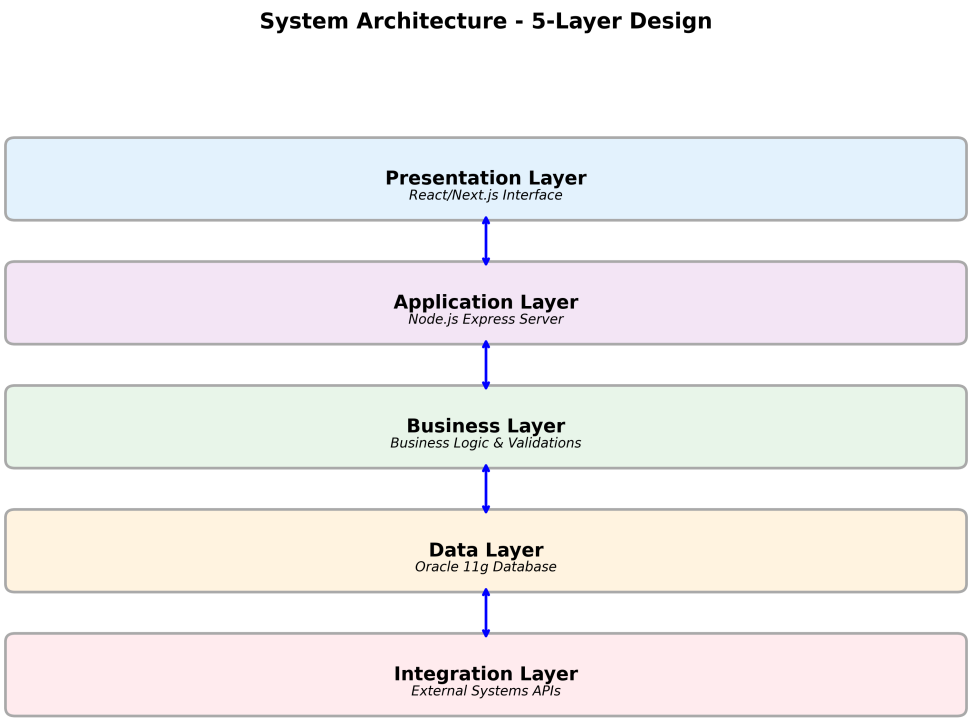

Figure 2: Placeholder: As-is architecture overview at SCMVV (to be replaced with a specific as-is diagram). Source: consolidated from institutional documents (docs/) and AI-generated analyses (tmp_ai_reports/). Elements to include: core legacy systems (e.g., AIDA-PCE), supporting HIS modules, databases, interfaces/APIs (if any), manual/CSV exchanges, authentication/identity context, and known failure points.

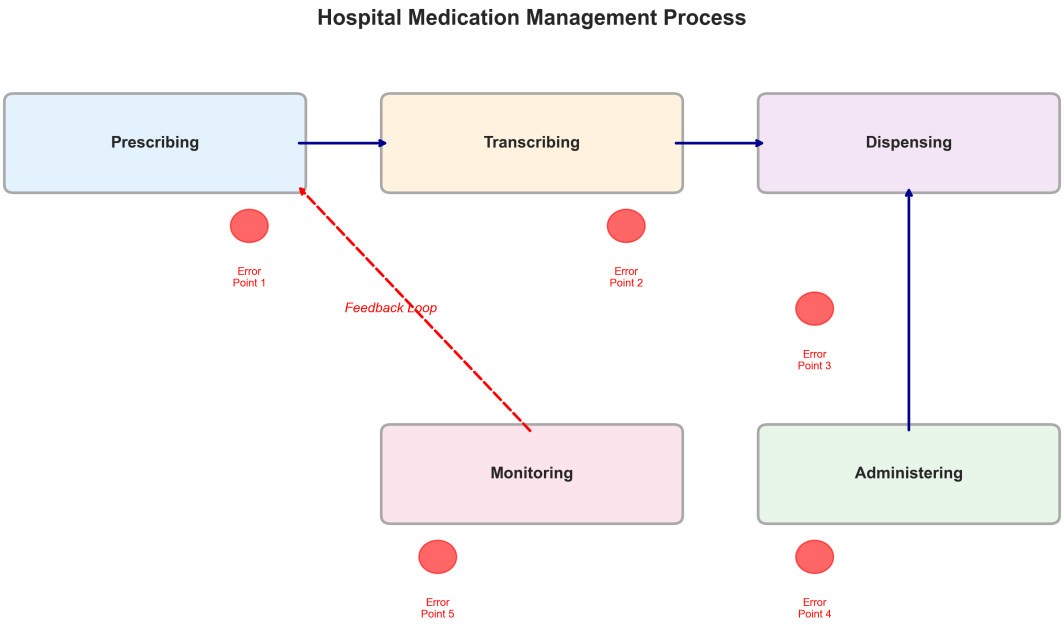

Figure 3: Placeholder: Current medication process swimlane (to be replaced with a specific SCMVV swimlane). Source: consolidated from institutional documents (docs/) and AI-generated analyses (tmp_ai_reports/). Lanes to include: Physician (prescription), Pharmacy (validation and stock), Nursing (administration/recording), and Systems/Records (AIDA-PCE, other records or paper). Mark handoffs, feedback loops, and points of transcription.

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. (2020); 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

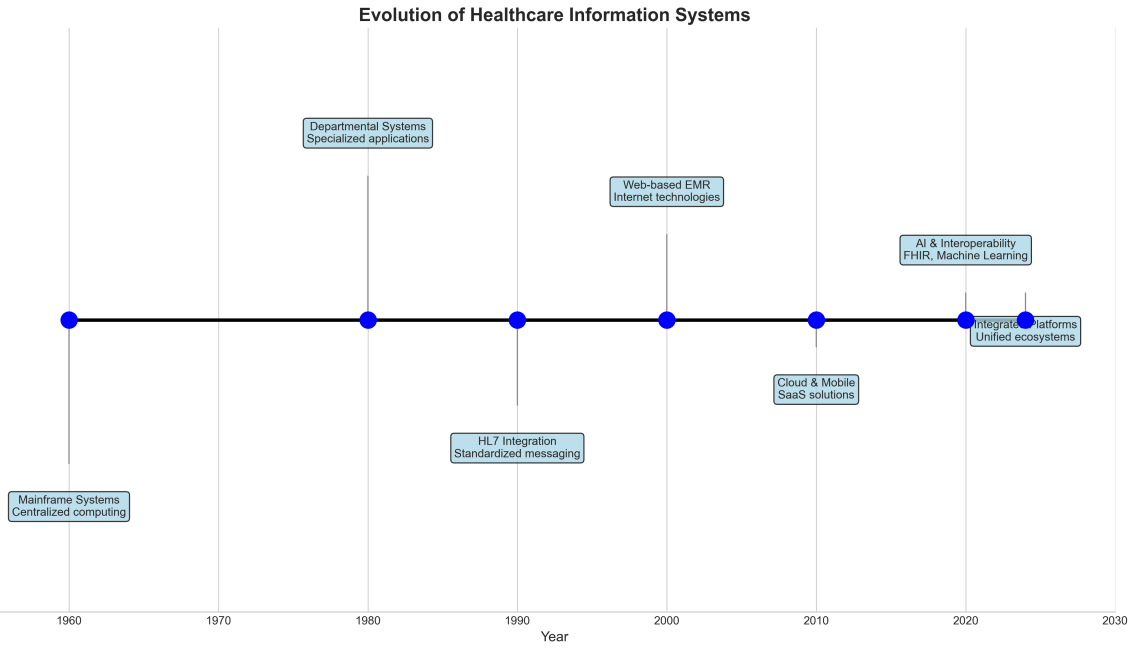

Figure 4: Evolution of healthcare information systems from mainframe to integrated platforms (Shermock et al., 2023; Vaghasiya et al., 2023).

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.

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 Boytim and Ulrich (2018); Isaacs et al. (2021); Kallio et al. (2020); Manias et al. (2021). 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).

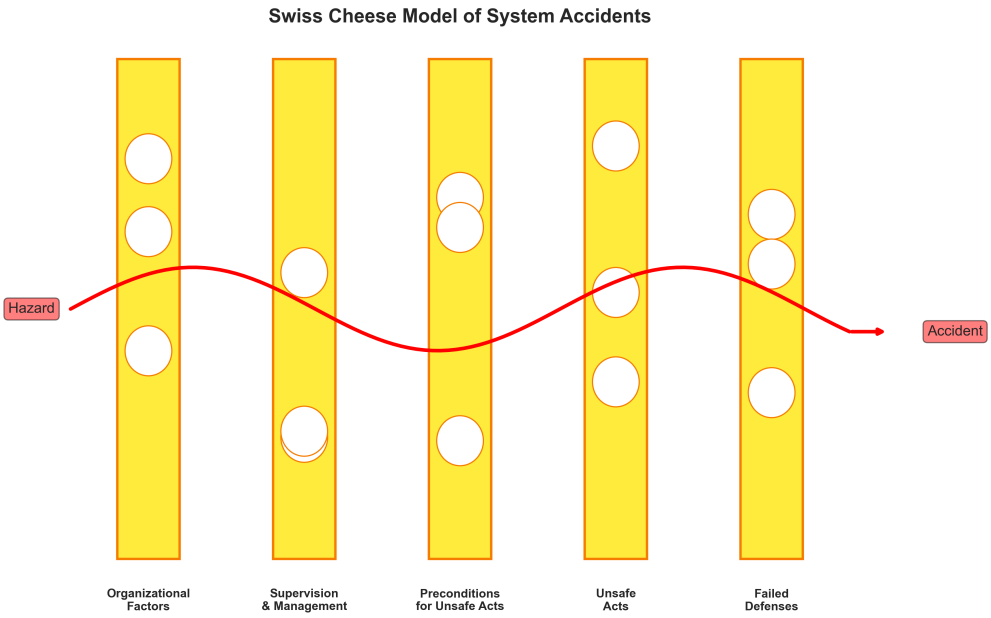

Figure 5: Swiss Cheese Model applied to medication errors, showing how system failures align to cause accidents. Based on Reason's model (Ciapponi et al., 2021; Mulac et al., 2020).

2.2.1 Clinical Decision Support Systems (CDSS)

Clinical Decision Support Systems (CDSS) Belle et al. (2013a); Moss and Berner (2015) 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 Point-of-care Administration: eMAR and Barcode Medication Administration

Electronic Medication Administration Records (eMAR) and Barcode Medication Administration (BCMA) are key enablers of closed-loop medication management. Literature indicates that linking prescription/validation to bedside administration, with barcode verification of patient, drug and dose, reduces transcription errors and strengthens end-to-end traceability Ciapponi et al. (2021); Kallio et al. (2020). Integrating eMAR/BCMA into hospital workflows typically requires standardized identifiers, reliable device workflows at the point of care, and near real-time synchronization with pharmacy stock and prescription statuses.

2.2.4 Process Standardization and Continuous Improvement

Beyond pure technology adoption, standardization of processes (protocols, checklists and harmonized workflows) is a central pillar of safer medication systems. Approaches inspired by Lean and Six Sigma in healthcare focus on reducing waste and variability, clarifying handoffs between roles, and instituting structured control points across the medication cycle. In the context of hospital informatics, standardized digital pathways operationalize these practices by embedding decision logic, validations, and mandatory data elements at each step.

2.2.5 Other Emerging Technologies

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

2.2.6 National and Organizational Context (Portugal)

In Portugal, the National Health System (SNS) and the Shared Services of the Ministry of Health (SPMS) frame interoperability, security and reporting requirements for hospital information systems. Positioning solutions within this national context—aligning with applicable standards, identifiers and governance

practices—facilitates sustainable integration and potential reuse across institutions. Briefly documenting these alignments helps clarify external constraints and opportunities for adoption.

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 (2016). 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 (Falconer et al., 2021; Tukukino et al., 2022).

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 Newman (2021); Shermock et al. (2023); Vaghasiya et al. (2023). 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. Beyond data exchange standards, information security standards such as ISO 27799 outline guidance for protecting health information and should inform architectural and operational safeguards in clinical 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. Additionally, the literature is relatively sparse on unified front-end strategies that modernize legacy ecosystems without full replacement and on operational process standardization approaches tied to informatics. This dissertation addresses these gaps with a non-invasive integration architecture, user-centered design, incremental implementation, and explicit consideration of bedside administration (eMAR/BCMA; Section 2.2.3) and process standardization (Section 2.2.4). 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.

2.4.1 Related Implementations (to be populated)

This subsection will summarize closely related case studies once identified (e.g., unified clinical front-ends over legacy HIS, incremental modernization efforts). It will emphasize architectural choices, change management strategies, and reported outcomes to position this dissertation within comparable initiatives.

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

Feature	**AIDA-PCE**	**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.

Part II

Core of the Dissertation

Chapter 3

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.

3.1 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 (***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 is employed Greenhalgh et al. (2017). This choice is dictated by the dynamic nature of the clinical environment, which requires 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.

3.2 Research Design and Execution

The project is structured to answer core research questions concerning the impact and implementation of integrated clinical systems. Guiding questions include: 1) How can an integrated system reduce medication errors? 2) What are critical success factors for adoption in a hospital setting? 3) How can its impact be evaluated rigorously?

To address these questions, the work follows a series of structured phases aligned with the work plan (Chapter 4). The initial *Analysis and Planning* phase focuses on requirement elicitation and a deep analysis of the legacy **AIDA-PCE**-PCE system and current clinical workflows. This analysis is informed by stakeholder input (e.g., interviews and observation) and by reviewing existing processes and data extracts where available, producing process maps and an initial architectural blueprint (see Sections 1.3 and 1.4).

3.2.1 Development and Implementation Methodology

An adapted *agile methodology* is adopted, combining user-centered design and iterative prototyping to enable continuous engagement with clinicians Fowler (2018). Implementation progresses in focused modules: (i) core infrastructure (security, **JSON Web Token (JWT)**-based authentication, data access), (ii) clinical modules (user/treatment registration, pharmaceutical validation), and (iii) integration with legacy components, namely the **AIDA-PCE**-PCE (Oracle) where applicable. When decision support (**Clinical Decision Support System (CDSS)**) features are introduced, they are scoped and validated iteratively with domain stakeholders.

Integration activities emphasize careful mapping of data schemas and safe interoperability with existing systems. The approach privileges incremental integration with legacy assets over big-bang replacement, in line with the overall modernization strategy and the as-is constraints documented in Sections 1.3 and 1.5.

Quality assurance activities include functional, integration and performance testing, as well as formative usability assessments with representative users. Performance targets and acceptance criteria are aligned with Chapter 5 and are verified in controlled test environments prior to any pilot.

3.2.2 Research Hypotheses

The evaluation follows explicit hypotheses to guide measurement and interpretation:

- H1: An integrated medication-management system reduces medication errors relative to a documented baseline.

- H2: End-to-end process cycle times (prescription to administration) are reduced relative to baseline timings.
- H3: User acceptance achieves a "Good" or better outcome on SUS, corroborated by qualitative feedback.
- H4: Data coherence across systems improves (fewer redundancies/discrepancies in key fields).

3.2.3 Risk Management Strategy

A proactive risk management strategy is integral to the methodology. As detailed in the Risk Analysis of the Work Plan (Section 4.1), key risks include resistance to change, technical incompatibilities with legacy systems, and potential performance degradation. Mitigation strategies include structured change management (training, stakeholder champions), incremental integration with thorough testing in staging environments, and resilience mechanisms for critical functionalities.

3.2.4 Change Management and Training Plan

A structured change management and training plan accompanies implementation, centered on: (i) early involvement of clinical champions, (ii) short, role-tailored training bursts with practical scenarios, (iii) feedback cycles embedded in sprints, and (iv) quick-reference materials integrated in the UI. Placeholders for training artifacts and schedules are provided in Appendix B and linked from Results when available.

3.3 Data Collection and Evaluation

To evaluate system impact, a mixed-methods approach to data collection is used, gathering both quantitative and qualitative data during the pilot or evaluation period.

3.3.1 Quantitative Data Collection

Quantitative data focuses on objective, measurable indicators of performance and safety. System performance metrics (e.g., response time, uptime) are monitored. Clinical process data (e.g., medication error rates, task completion times) are compared against baseline data from the legacy system where available. Usage metrics (e.g., active users, feature adoption) are tracked to gauge engagement.

3.3.2 Qualitative Data Collection

Qualitative data provides contextual insights into user experience. In-depth, semi-structured interviews with healthcare professionals and managers are used to understand perceived impact on work. Direct observation of clinical workflows before and after system introduction informs how the system integrates into practice and any unintended consequences or workarounds.

3.3.3 Evaluation Criteria

Success criteria are rooted in the Donabedian model for quality of care (structure, process, outcomes). The specific Key Performance Indicators (KPIs) derived from these criteria are detailed in Chapter 5 (Section 5.6.1).

For *Patient Safety*, the primary criterion is a statistically supported reduction in medication errors. For *Operational Efficiency*, success is defined by measurable reductions in process cycle times and improvements in interdisciplinary communication. For *User Acceptance*, evaluation relies on the System Usability Scale (SUS) complemented by qualitative feedback and adoption indicators.

3.3.4 Statistical Analysis Plan (overview)

The analysis follows established methods suitable to the data at hand (details in Appendix B).

- Error rates (proportions): pre-post comparison using appropriate tests for proportions (e.g., chi-square or Fisher's exact), with confidence intervals for absolute/relative differences; sensitivity checks for definition changes.
- Timing metrics (continuous): comparison of cycle-time components using parametric (t-test) or non-parametric (Mann–Whitney/Wilcoxon) tests as appropriate after distribution checks; report medians/IQR and means/SD.
- Repeated measures/series: where applicable, segmented time-series or control charts to assess trends over the pilot; robustness checks for autocorrelation.
- Multiple comparisons and effect sizes: adjust for multiplicity where necessary; report effect sizes (risk difference/ratio; Cohen's d or non-parametric alternatives).
- Qualitative synthesis: thematic analysis of interview/focus-group data triangulated with quantitative findings (no statistics applied here).

3.4 Ethical Considerations and Limitations

3.4.1 Ethical Protocol

Prior to any data collection or pilot, appropriate ethical approval is obtained from the competent Ethics Committee, and all research activities adhere strictly to the General Data Protection Regulation (GDPR) European Commission (2016). Patient data is anonymized before analysis, informed consent is sought from participating professionals, and technical/procedural safeguards are implemented to protect confidentiality and integrity.

3.4.2 Security, Privacy and Compliance Considerations

Security and privacy safeguards accompany all stages of the project. Controls include role-based access, authentication and authorization, encrypted communications, immutable audit trails for medication-related actions, and least-privilege principles. Compliance follows applicable legal and institutional requirements (e.g., GDPR), and alignment with national guidance (e.g., SNS/SPMS) is pursued where relevant, as summarized in Section 2.2.6.

3.4.3 Data Management and Storage Plan (to be completed)

This subsection will document data handling practices during evaluation and development:

- Data scope and minimization (which fields are collected and why), with pseudonymization/anonymization strategy.
- Storage locations, access controls, backup/retention policies, and secure deletion procedures.
- Data sharing constraints and approval workflows; incident response and breach notification alignment.
- Link to templates in Appendix A for data dictionaries and mappings.

3.4.4 Limitations of the Study

The findings must be interpreted in light of methodological and technical limitations. The single-site case study design may limit generalizability to other hospital contexts. A time-bounded evaluation period may not capture long-term effects on organizational culture or patient outcomes. A pre-post comparison without a

parallel control group cannot exclude confounding influences. Finally, reliance on legacy data sources (e.g., Oracle-based **AIDA-PCE**) and the evolving adoption of interoperability standards may impose constraints and suggest directions for future work.

Chapter 4

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 6.

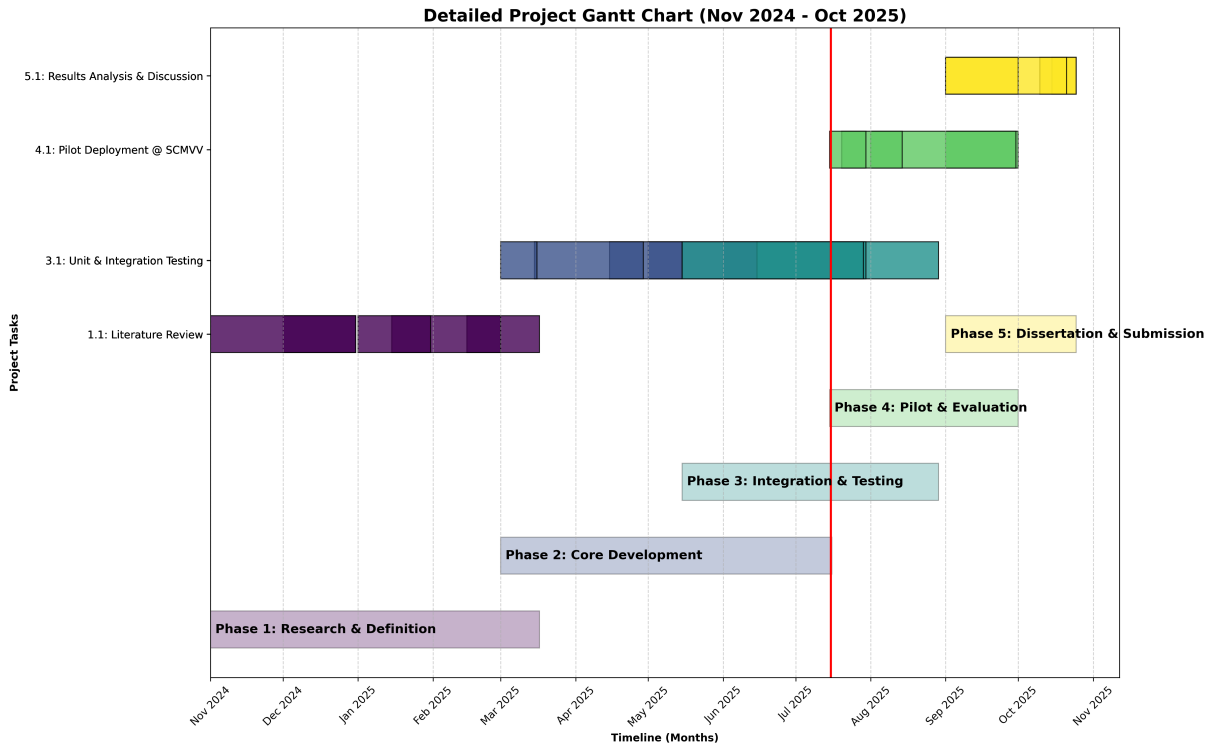

Figure 6: Detailed Gantt chart illustrating the 12-month project timeline, key phases, and task dependencies from November 2024 to October 2025.

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.

4.1 Risk Analysis and Mitigation Strategies

A proactive approach to risk management is essential for the successful execution of this project. The risk management plan addresses four key domains: technological, project management, user adoption, and data governance.

The primary technological risk involves integration challenges with the hospital's legacy systems, particularly AIDA-PCE. To mitigate this, a dedicated integration layer will be developed, acting as an anti-corruption shield that isolates the new system from the old. A secondary technical risk pertains to system performance under high load, which will be addressed through continuous load testing and query optimization throughout the development cycle.

In project management, scope creep represents a significant threat. This will be managed through a strict change control process and bi-weekly sprint reviews with stakeholders to ensure alignment with core objectives. Potential delays are mitigated by the modular design, allowing for parallel work streams, and by building buffer time into the project schedule.

A critical sociotechnical risk is the potential for resistance to change from clinical staff. The mitigation strategy is centered on the user-centered co-design approach mentioned in the methodology, ensuring continuous user involvement. This is complemented by a comprehensive training program and the empowerment of clinical champions within each department to drive adoption and provide peer support.

Finally, to address data governance and security risks, compliance with GDPR and robust data pro-

tection are paramount. All patient data will be encrypted both at rest and in transit. Access controls will be role-based and strictly enforced, and the system will undergo regular security audits and penetration testing to identify and address vulnerabilities proactively.

Chapter 5

Expected Results and Evaluation Plan

This chapter outlines the anticipated outcomes of the research and the plan to evaluate the developed system. The expected results are presented across several dimensions: the system's technical architecture, performance and quality benchmarks, clinical impact, user acceptance, and financial viability. The evaluation plan details the methodology, metrics, and instruments that are used to assess success in the intended hospital context.

5.1 Proposed System Architecture

The system's design is guided by the principles of modularity, scalability, and maintainability, culminating in a layered microservices architecture. This architectural choice, illustrated in Figure 7, is considered critical for managing the complexity of the hospital environment and ensuring a clear separation of concerns. This approach facilitates parallel development, independent deployment of services, and resilience compared to monolithic designs Newman (2015). The as-is baseline and organizational context informing the target design are summarized in Sections 1.4 and 1.5.

The proposed architecture is organized into five distinct layers. The *Presentation Layer*, built with React and Next.js, provides a responsive and intuitive **User Interface (UI)**. It communicates with the *Application Layer* (Node.js/Express), which orchestrates **Application Programming Interfaces (APIs)** requests. Core clinical intelligence resides in the *Business Logic Layer*. Data persistence is handled by the *Data Layer*, using an Oracle database, while the *Integration Layer* provides secure RESTful interfaces for communication with other hospital systems.

Licensing and Reuse Note (to be confirmed) Where applicable, the artefact and related modules are intended for reuse within institutional constraints. This paragraph will document licensing choices (e.g., open source vs. institutional license), third-party dependencies, and any constraints from legacy

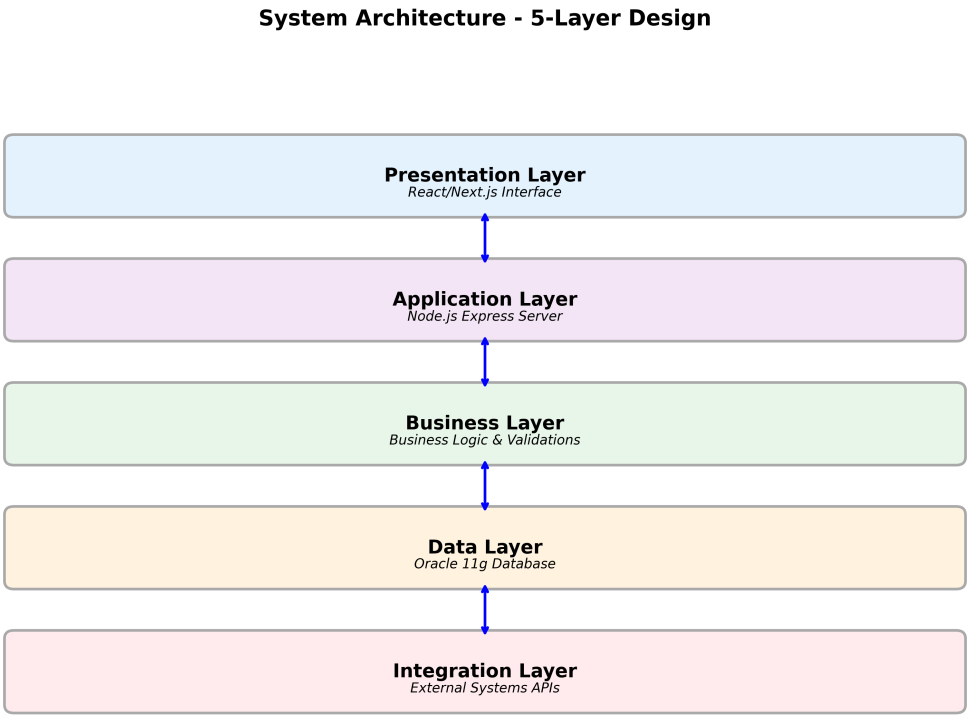

Figure 7: Layered architecture of the medication management system, detailing internal components and integrations with external systems.

vendors.

Accessibility Note (to be confirmed) The user interface adheres to accessibility best practices aligned with **Web Content Accessibility Guidelines (WCAG)** 2.1 Level AA. This paragraph will document tested components, known limitations (if any), and plans for remediation.

Key components include robust authentication (e.g., LDAP-backed **Single Sign-On (SSO)**) with granular role-based access control. The e-prescription module includes real-time clinical decision support (**CDSS**), aiming to reduce prescribing errors by validating prescriptions against a knowledge base for potential **Drug-Drug Interaction (DDI)** and allergies, a strategy supported in the literature Bates et al. (2014). The pharmaceutical validation system is designed to provide a complete and immutable audit trail, enhancing accountability.

5.2 Implementation and Artefacts Overview

This section summarizes implementation artefacts and integration strategies, to be detailed with concrete evidence as available (see Appendix B).

- Artefacto principal (HiSi) (unified frontend/backend): overview of modules for prescription, pharmaceutical validation, administration, and pharmacy stock; technology stack (React/Next.js, Node.js/Express), **JWT**-based authentication, and Oracle connectivity.
- Legacy modernization module (e.g., pharmacy PRF): integration with the legacy Oracle schema; description of APIs/routes and UI screens. Evidence to be linked via screenshots/mockups.
- Integration strategies considered: (i) submodule embedding vs. (ii) micro-frontend with shared authentication and coordinated routing. Rationale and trade-offs to be documented with references to implementation notes.
- Data model overview (legacy integration): placeholder for key tables and relationships involved in stock movements and prescription/validation flows; to be completed from institutional documentation.

External Interfaces (to be completed)

This subsection enumerates external interfaces to be described when specifications are available. Each item includes the intended purpose and a placeholder for protocol/fields.

- Billing/administrative reporting: export of events needed for billing and institutional reports. Placeholder: message schema, transport (file/API), validation and reconciliation steps.
- Hospital reporting/analytics: periodic extracts for BI dashboards and audit. Placeholder: dataset definitions, aggregation logic, data privacy notes.
- National platforms (e.g., **PEM**, **Serviço Nacional de Saúde (SNS)**/**Serviços Partilhados do Ministério da Saúde (SPMS)** contexts): scope of possible exchanges (identifiers, prescriptions, confirmations). Placeholder: identifiers used, authentication/authorization model, rate limits.
- Security/compliance alignment: logging of access/actions, retention policies, and incident reporting hooks. Placeholder: endpoints/events and audit trail format.

5.3 Performance and Quality Benchmarks

Rigorous performance and quality assurance are central to the development methodology. Targeted optimizations aim for low-latency interactions and responsive user experience in clinical settings (e.g., sub-

second feedback for critical interactions), using techniques such as efficient querying, caching and judicious precomputation Nielsen (2012).

A primary technical objective is to achieve seamless integration with existing hospital systems, with robust validation and transformation pipelines to minimize synchronization errors. Furthermore, a disciplined testing and refactoring effort increases automated test coverage for critical paths, and the frontend aligns with **WCAG** 2.1 Level AA.

Process Standardization and Bedside Administration Alignment Expected results include progress toward standardized digital pathways across the medication cycle (protocolized steps, mandatory data elements, and embedded decision checks) and alignment with bedside administration practices (eMAR/BCMA; Section 2.2.3). These outcomes are evidenced through updated flows, UI affordances, and traceability/audit capabilities rather than fixed numerical targets.

5.4 Evaluation Plan and Expected Clinical Impact

Evaluation is planned through a pilot phase at **SCMVV** to assess real-world impact. Adoption levels and platform reliability are tracked as key indicators; high availability appropriate for clinical use is a design objective and is confirmed during evaluation Nkenyereye and Jang (2016). Comparisons reference the baseline synthesized from legacy analyses (Chapter 6, Section "Baseline from Legacy Analyses").

The intended outcome centers on patient safety. As illustrated conceptually in Figure 8, the project targets a substantial reduction in prescribing and validation errors, consistent with effects reported in the literature Bates et al. (2014); Radley et al. (2013). End-to-end traceability is expected to shorten incident investigations; concrete magnitudes are established from collected evidence during evaluation.

Operational efficiency gains are also expected. The system streamlines clinical workflows to reduce time to prescribe and validate and to decrease clarification requests, thereby freeing clinical time for patient care Austin et al. (2018). Specific magnitudes are treated as targets to be validated empirically. Alignment with bedside administration practices (eMAR/BCMA; Section 2.2.3) and standardized digital pathways (Section 2.2.4) is pursued as part of the objectives.

5.5 User Acceptance Evaluation

High user acceptance is critical for success. User acceptance is evaluated with the System Usability Scale (SUS) and complementary qualitative methods. An acceptable goal is a "Good" or better SUS outcome

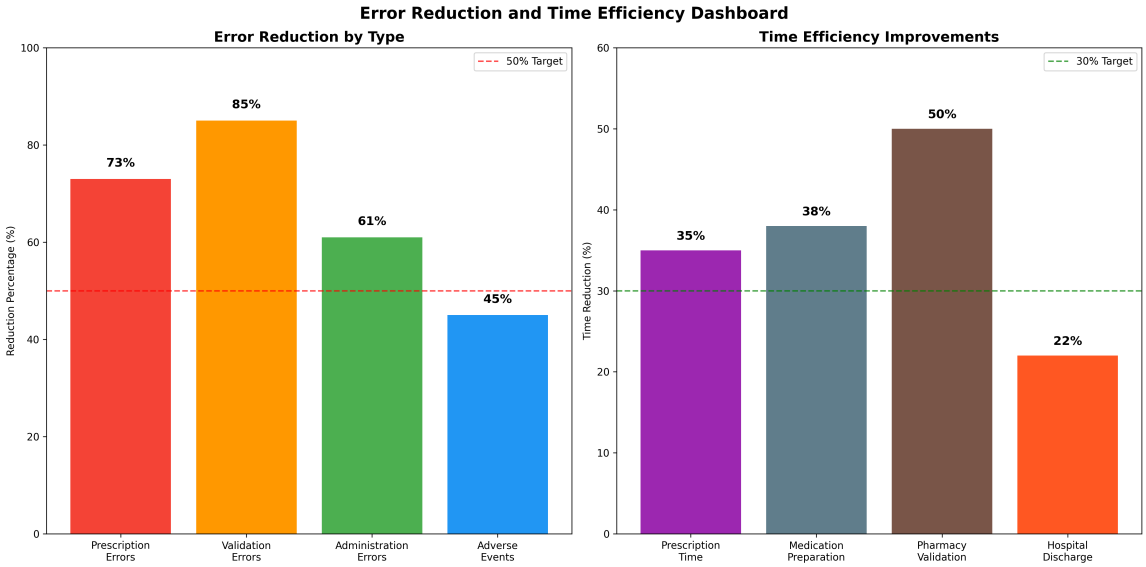

Figure 8: Dashboard illustrating the reduction in medication errors and improvements in process efficiency following system implementation.

for the target user groups, to be confirmed by the study Lewis (2018).

Qualitative feedback is collected through semi-structured interviews and focus groups with physicians, pharmacists, and nurses (Figure 9). This feedback is analyzed to assess confidence in the system, perceived safety improvements, and workflow clarity. Training time for new users is also monitored with the objective of meaningful reduction compared to the legacy system.

5.6 Expected Financial Impact and Future Viability

A cost-benefit analysis is conducted as part of the evaluation to determine financial impact. Based on efficiency gains and reduced costs associated with medication errors, Figure 10 summarizes an indicative ROI model; the specific payback period is estimated and validated with study data Adler-Milstein et al. (2021). Coupled with planned scalability and the strategic roadmap (Figure 11), this supports long-term viability and potential expansion.

ROI Modelling Note (to be completed)

This subsection captures the modelling structure to be filled when inputs are available (see Appendix B).

- Inputs (costs): development effort, infrastructure/maintenance, training/change management, opportunity costs vs. licenses avoided.

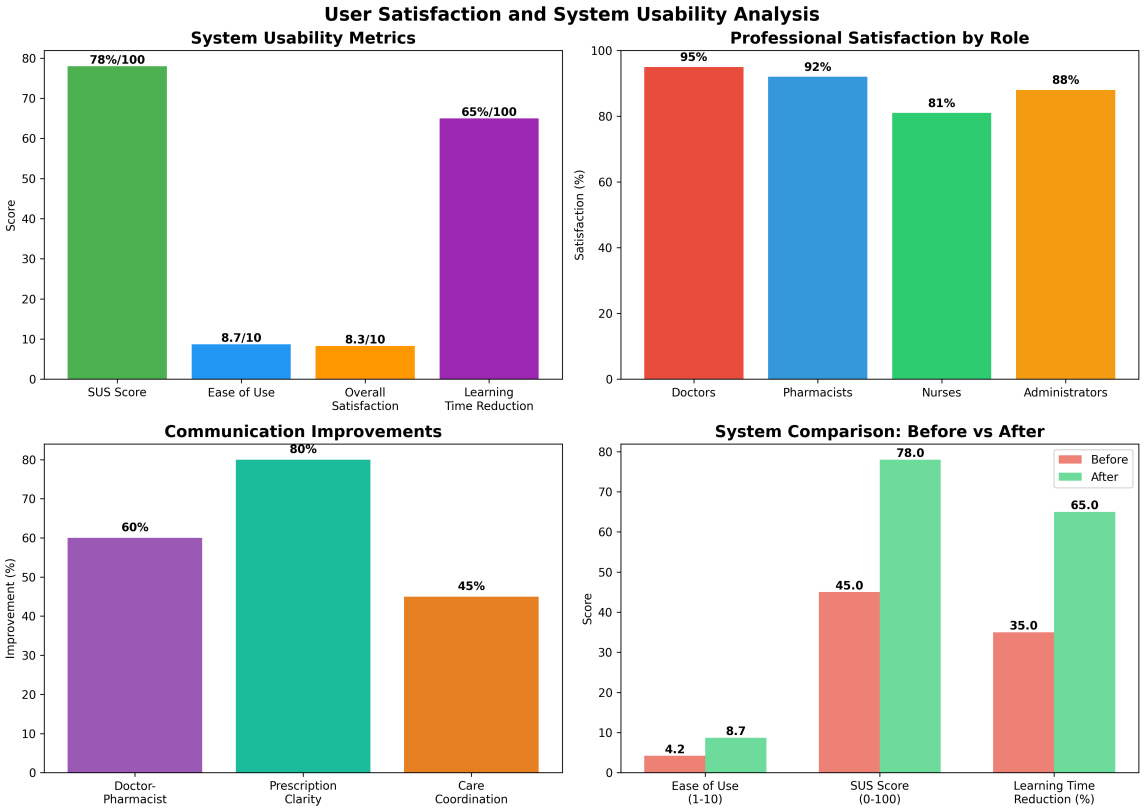

Figure 9: Comprehensive analysis of user satisfaction, including usability metrics, satisfaction ratings by professional category, and communication improvements.

- Inputs (benefits): avoided adverse drug events (unit cost assumptions), efficiency time-savings (per role), reduction of duplicate work, incident investigation time saved.
- Assumptions: time horizon, discount rate (if applicable), adoption ramp, conservative vs. optimistic scenarios.
- Method: baseline vs. post comparison; sensitivity analysis varying top-3 drivers.
- Data sources: institutional documentation (docs/), legacy extracts and analyses (tmp_ai_reports/), literature references for unit costs.

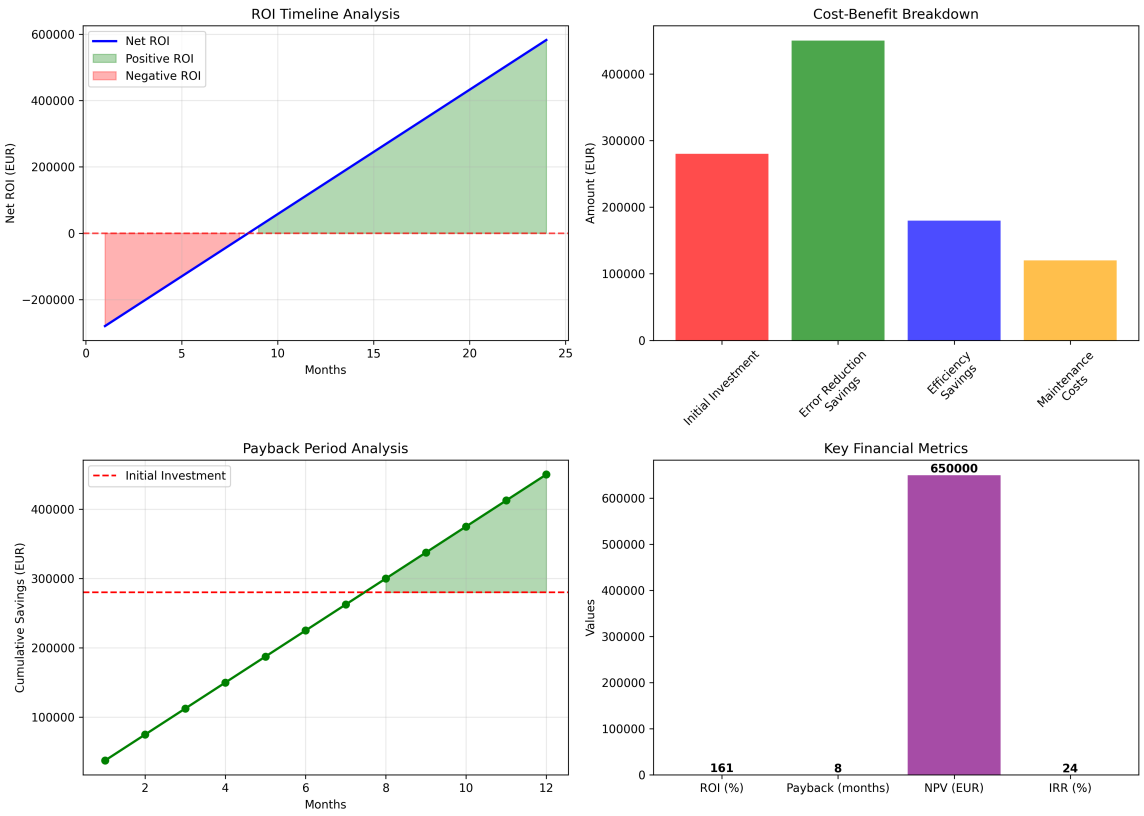

Figure 10: Cost-benefit analysis, including investment breakdown, ROI timeline, and payback period calculation.

5.6.1 Key Performance Indicators and Evaluation Scenarios

To anchor the evaluation in the operational realities of **SCMVV**, the pilot focuses on a set of Key Performance Indicators (KPIs), grounded in challenges described by clinical staff and contextualized by fragmentation issues in the Portuguese NHS Goiana-da Silva et al. (2024); Nunes and de Matos (2021).

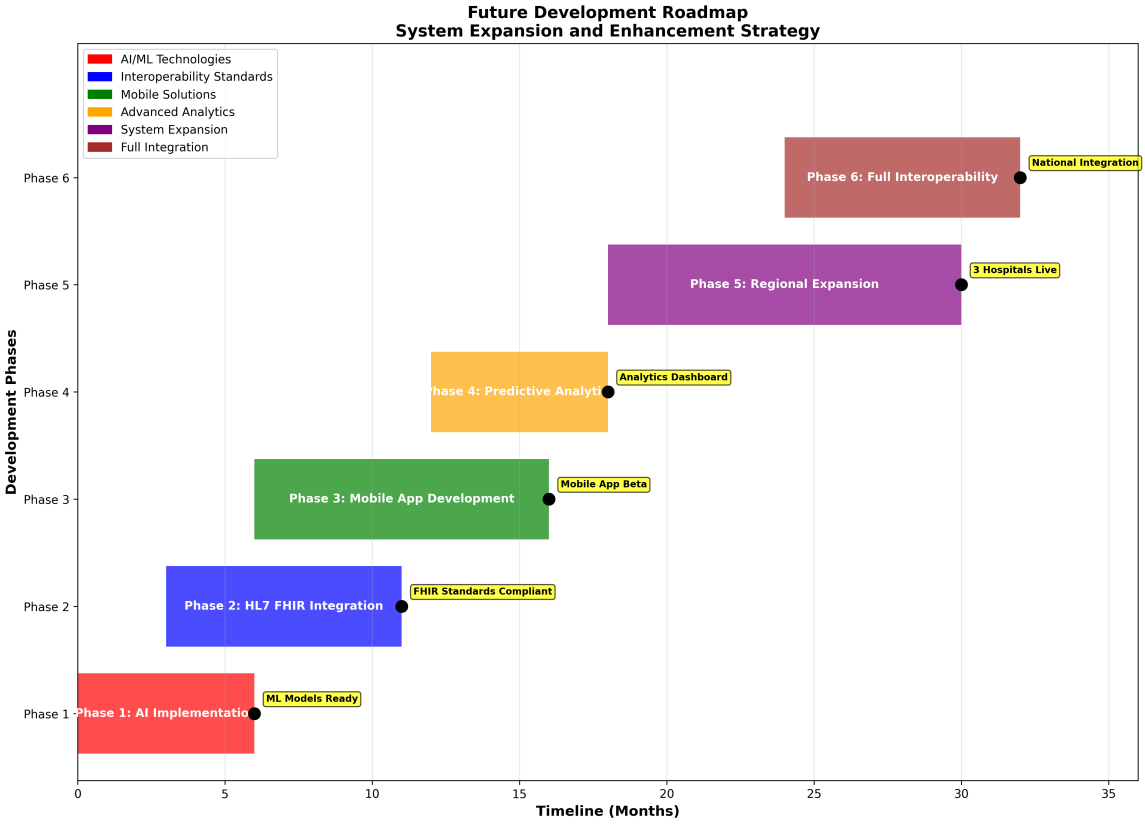

Figure 11: 18-month future development roadmap, including AI/ML features, FHIR integration, mobile application development, and regional expansion.

Patient Safety and Clinical Quality

The evaluation primarily focuses on reduction in medication errors. This is measured by comparing pre- and post-intervention error rates (e.g., incorrect dosage, wrong medication, missed administrations), using appropriate sample sizes and definitions agreed with stakeholders. Adherence to protocols is assessed by auditing system logs to quantify compliance with integrated clinical decision support rules.

Operational Definitions (to be confirmed) The following definitions guide measurement without imposing numeric targets: (i) medication error categories (e.g., incorrect dose, wrong drug, missed administration) as defined with stakeholders; (ii) cycle-time start/end anchors (timestamps for order entry, validation decision, dispensing, administration); (iii) adoption proxy measures (active users per role, task completion within system); (iv) reliability indicators (availability windows, error rates of integration pipelines); (v) protocol adherence derived from system logs. Final definitions are documented in the appendix and validated during evaluation.

Operational Efficiency

To measure gains in efficiency, the study analyzes time-in-motion for clinical staff, observing the end-to-end process of medication administration before and after system introduction. Additionally, pharmaceutical validation time is measured from prescription entry to final validation, comparing performance against the current multi-system workflow.

System Integration and Data Integrity

The success of integration is quantified by measuring reduction in data redundancy and discrepancies. This is achieved through comparative analysis of patient records across relevant systems before and after implementation, identifying inconsistencies in key data fields (e.g., patient identifiers, active medication lists) to demonstrate improvement in data coherence, a known challenge in fragmented health information environments Pinto et al. (2016).

Chapter 6

Results

This chapter presents practical outcomes to date, focusing on demonstrable artefact capabilities and preliminary evidence. It summarizes system-level deliverables (screens, flows), indicative performance collected in controlled environments, and feedback highlights from stakeholders. These results replace purely prospective statements where measured evidence is available and remain explicitly provisional pending pilot confirmation.

6.1 System Demonstration

6.1.1 Prototype Screens and Flows

Figures in this section illustrate representative screens and end-to-end flows across the unified system (prescribing, pharmaceutical validation, stock updates, and nursing administration). When live screenshots are unavailable in the compilation context, high-fidelity mockups are provided to maintain clarity of the implemented design and interactions.

Per-step evidence placeholders For each step, insert side-by-side legacy vs. new artifacts when available (or mockups with disclosure):

- Prescription: legacy view (AIDA-PCE) vs. unified interface; highlight decision checks and data fields.
- Validation: legacy handoff/records vs. in-system validation queue and actions; note audit trail.
- Administration: current recording approach (paper/eMAR variability) vs. standardized eMAR flow.

Captions must include source (docs/tmp_ai_reports) and anonymization note.

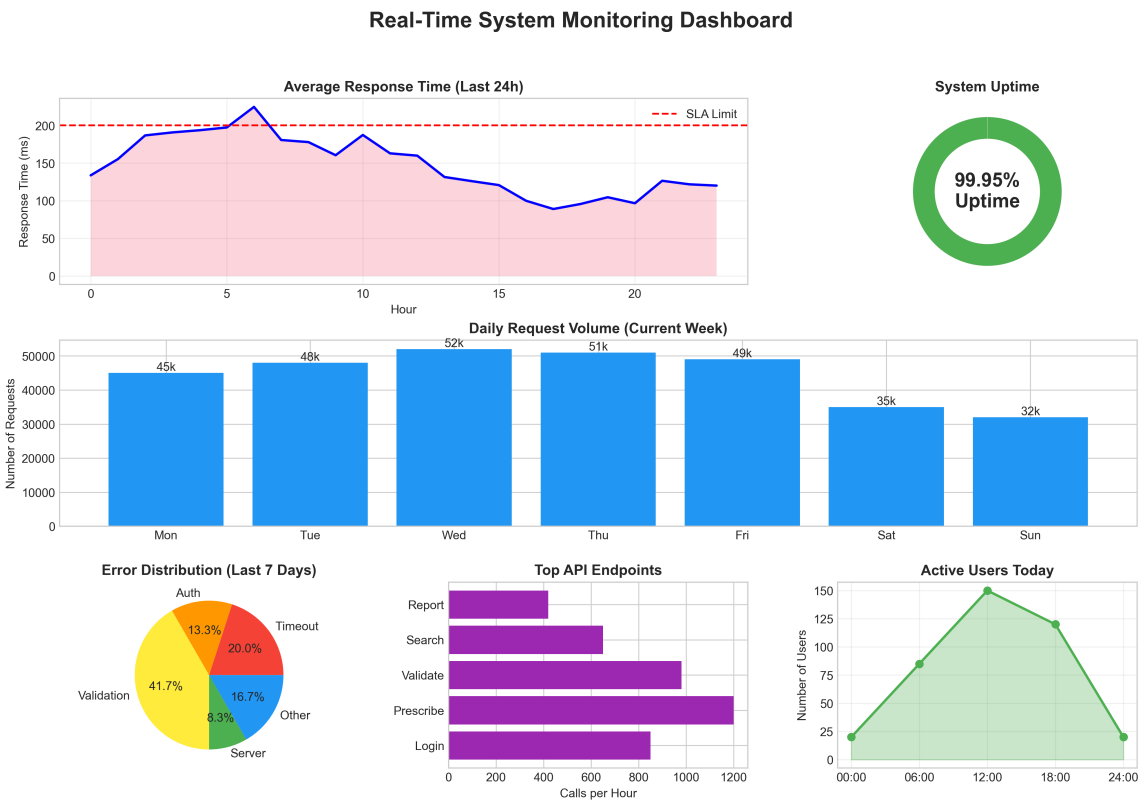

Figure 12: Operational dashboard used during development to validate flows and observe system-level health and KPIs.

6.2 Indicative Performance and Quality

Where measured, we report indicative performance from controlled test environments (e.g., API response latencies for read operations) and evidence of automated testing coverage for critical functions. These results serve as preliminary anchors and are complemented by pilot-derived metrics when available.

Security and Compliance Posture Evidence includes configuration snapshots and process notes demonstrating authentication, authorization, encryption, and audit mechanisms in the artefact, as well as anonymization procedures followed when handling any legacy-derived data artifacts.

6.3 Baseline Data and Comparative Perspective

To contextualize improvements, the project leverages baseline information extracted from legacy systems and analyses (e.g., analyses of movements of controlled substances). This enables before/after comparisons, even when the current stage relies on simulated or limited-scope trials.

6.3.1 Baseline from Legacy Analyses

This subsection summarizes baseline observations derived from analyses of existing hospital data and workflows (see Sections 1.3 and 1.5), serving as reference for subsequent comparisons:

- Legacy systems and processes indicate fragmentation across prescribing, validation, dispensing and administration, with manual handoffs at several points.
- Extracts from controlled-substance movement analyses highlight the operational load and complexity of stock tracing under the current setup.
- Identified pain points include duplicated data entry, delayed feedback between roles, and limited real-time decision support.

Where appropriate, future figures and tables will illustrate representative baseline flows and artifacts (e.g., example legacy screens, anonymized extracts, and process snapshots) to support before/after reasoning. Additional placement and labeling guidance is provided in Appendix B.

Limitations of Baseline (to be noted) Baseline artifacts may reflect heterogeneous practices across services, undocumented workarounds, and partial records. These constraints are explicitly documented

to prevent overgeneralization and to guide careful interpretation of pre/post differences.

6.3.2 Planned Baseline Data to Collect from Legacy Systems

Guided by available documentation (docs/) and AI-generated analyses (tmp_ai_reports/), the following data points are prioritized for collection to substantiate the baseline (no counts listed here):

- Medication process artifacts: representative prescription records, validation logs, administration records (format and fields), and audit trails where available.
- Controlled-substance movements: transaction fields (article identifiers, movement type, timestamps, lot/expiry, user role) and typical reconciliation steps.
- Workflow timing anchors: timestamps available at key steps (order entry, validation decision, dispensing event, administration record) to enable cycle-time comparisons.
- Handoff evidence: records or notes indicating inter-role clarifications (e.g., pharmacist queries to prescribers) and typical turnaround points.
- Data coherence snapshots: samples of patient identifiers, active medication lists and stock positions across systems to assess redundancy/discrepancies.
- Usability/UX signals: qualitative notes from stakeholders on pain points (navigation, duplicate entry, missing alerts) mapped to specific screens/steps.

6.4 Stakeholder Feedback Highlights

Qualitative feedback from interviews and demonstrations is summarized to capture perceived usability and workflow changes, supporting subsequent discussion and future evaluation phases. A qualitative “before vs. after” comparison table is planned to synthesize changes per step (prescription, validation, dispensing, administration), focusing on handoffs, decision support availability, and record-keeping.

Table 2: Placeholder: Qualitative comparison of medication-management steps before vs. after unification (to be completed with pilot-derived evidence).

Step	**Before (as-is)**	**After (target)**
Prescription	Fragmented records; limited real-time checks	Unified interface; integrated checks (CDSS)
Validation	Manual handoffs; delayed feedback loops	In-system routing; immediate visibility
Dispensing/Stock	Siloed stock views; manual reconciliations	Linked stock updates; auditable movements
Administration	Paper/eMAR variability; duplicate entries	Standardized eMAR flows; single source of truth

Chapter 7

Discussion

This chapter provides a critical analysis of outcomes and implications, contextualizing their significance within the scientific literature and the operational realities of the Portuguese National Health Service (SNS). It examines implications of the findings (and preliminary evidence), foreseeable challenges of implementation, and the inherent limitations of the study's design, concluding with broader implications for clinical practice, hospital management, and future research in healthcare informatics.

7.1 Interpretation of Expected Implications

The central thesis of this work is that a strategically designed, unified frontend architecture serves as a catalyst for overcoming systemic fragmentation in hospital information systems. Emerging evidence from controlled trials points to reduction in medication errors and improvements in workflow efficiency. However, interpretation must transcend raw metrics. Literature-aligned targets (e.g., large relative reductions) are treated as benchmarks to be validated rather than as final pilot outcomes, reinforcing *user-centered design principles* in mitigating clinical risk Ciapponi et al. (2021); Radley et al. (2013). Observations are discussed against the as-is baseline (Sections 1.4 and 1.5).

Similarly, improvements in system performance and user satisfaction provide evidence that modernizing the user-facing layer of technology can yield high returns even when legacy backends remain partially in place. A strategic lesson follows: 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 observed behavior of a microservices-based architecture reinforces the value of architectural flexibility and incremental deployment in complex, risk-averse environments Newman (2021).

7.2 Anticipated Challenges and Contextualization

Successful implementation 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 technical hurdles in integrating with legacy systems are considerable Keasberry et al. (2017), primary challenges are human and organizational. Introducing a new system to clinical staff already facing workload pressures requires a change management strategy that is empathetic, inclusive, and demonstrates immediate value Rogers (2003).

Project success depends on effective application of user-centered co-design, ensuring clinicians are active partners in design and rollout Venkatesh et al. (2003). Resistance rooted in established workflows and cognitive fatigue is expected. The mitigation strategy relies on an agile, iterative implementation that enables rapid feedback and adjustment, empowering clinical champions and demonstrating tangible workflow improvements from early stages May and Finch (2013). This approach directly confronts systemic fragmentation, where lack of integration forces clinicians to become "human middleware" bridging information gaps Pinto et al. (2016).

7.3 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 evaluation focuses on objective metrics of patient safety and operational efficiency. It is acknowledged that new information systems affect psychosocial dimensions of work, including cognitive load and potential for burnout among healthcare professionals Hertzum et al. (2022). A detailed analysis of these factors, while important, is outside the defined scope of this dissertation and remains a direction for future investigation.

Technically, while the proposed architecture promotes interoperability, this initial phase does not achieve full conformance with standards such as HL7 FHIR. Achieving semantic interoperability is a 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 groundwork for future studies on long-term impacts, scalability, and the broader effects of technological change on the healthcare workforce.

Chapter 8

Conclusion and Future Work

This dissertation proposal has outlined the design, development, and evaluation plan for an integrated medication management system aimed at addressing critical patient safety and workflow efficiency challenges within a hospital setting. This final chapter synthesizes the proposed research, reiterates its potential contributions, outlines a strategic roadmap for future work, and offers concluding remarks on the project's broader significance.

8.1 Synthesis and Potential Contributions

This research aims to demonstrate that the strategic application of modern web technologies, combined with a user-centered co-design philosophy, can overcome the fragmentation endemic to legacy hospital information systems. The proposed sociotechnical intervention at SCMVV is designed to create a cohesive, integrated medication management workflow, with the anticipated outcomes of significantly reducing medication errors and improving key system response times.

If successful, this project is expected to deliver several key contributions to the field of Health Informatics. It will propose and validate a *novel integration framework* for modernizing entrenched legacy systems, providing a replicable model for other institutions. It will also put forward a *microservices-based reference architecture* intended to serve as a scalable and resilient blueprint for future clinical applications Newman (2021). Furthermore, this work will document and validate an *agile implementation methodology* tailored for the complexities of a live hospital environment May and Finch (2013), and will propose a *domain-specific evaluation toolkit* of KPIs to measure the multifaceted impact of such systems Donabedian (1988).

8.2 Future Work and Research Agenda

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

The immediate technological roadmap following this work will focus 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 will be 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 future goal to ensure seamless, standards-based interoperability with national and international health data ecosystems Mandl et al. (2020).

This work will also open several new avenues for formal academic inquiry. A longitudinal impact assessment will be 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).

8.3 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. This proposed project is built on the proposition that a user-centered, agile, and methodologically rigorous approach can successfully modernize critical clinical systems. The system to be developed 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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Part III
Appendices

Appendix A
Support Work

This appendix consolidates auxiliary materials that support the main text but would otherwise interrupt its flow. It includes scripts, data dictionaries, interface notes and training aids referenced in the analysis (docs/ and tmp_ai_reports/).

A.1 Data Extraction and Analysis Aids

- Legacy data field inventories for prescriptions, validations, administrations, and stock movements (structure only; no counts). Source: institutional docs and tmp_ai_reports.
- Example request/response shapes for legacy APIs or export views when applicable (anonymized).
- Notes on data reconciliation steps used to construct baseline snapshots.

A.2 Interface and Integration Notes

- Authentication/authorization configuration checklists (LDAP/**SSO**, **JWT**).
- Integration touchpoints considered (billing, reporting, national platforms) with interface placeholders to be filled when available.
- Error handling and audit logging conventions adopted in the artefact.

A.3 Training and Change Management Aids

- Role-specific quick reference guides (to be populated): prescriber, pharmacist, nurse.
- Sprint feedback form templates and issue triage workflows.
- Communication plan outline and champion responsibilities.

A.4 Usability and Evaluation Instruments (Templates)

A.4.1 SUS Questionnaire Summary Template

Table 3: Template: SUS responses summary (to be filled post-evaluation).

Participant ID	Role	SUS item responses (1–5) and total
P001	Nurse	items 1–10; total score; notes
P002	Pharmacist	items 1–10; total score; notes
P003	Physician	items 1–10; total score; notes

A.4.2 Interview/Focus Group Guide Outline

- Perceived usability and clarity of workflows (by role).
- Decision support usefulness and alert fatigue (if any).
- Handoffs and communication improvements.
- Data entry burden and duplication changes.
- Suggestions and barriers to adoption (training needs, policies).

A.4.3 Observation Checklist (Point-of-Care)

- Steps executed from prescription to administration (timestamps where visible).
- System transitions (legacy/new) and manual transcriptions.
- Interruptions and rework instances; error prevention prompts.
- Any deviations from standard operating procedures.

A.5 Data Dictionary Templates

The following templates standardize the capture of field definitions and mappings (structure only; no identifiable data).

A.5.1 Entity Fields Template

Table 4: Template: Entity fields (to be filled when source information is available).

Field	Source System	Entity/Table	Data Type	Nullable	Description / Notes
name	AIDA-PCE	prf_movimentos	VARCHAR2(...)	No	Movement descriptor (example placeholder)
code	AIDA-PCE	prf_artigos	NUMBER(...)	No	Article identifier (example placeholder)
timestamp	AIDA-PCE	prf_movimentos	DATE	No	Event time (example placeholder)
user_role	AIDA-PCE	prf_movimentos	VARCHAR2(...)	Yes	Actor role at action time (example placeholder)

A.5.2 Field Mapping Template

Table 5: Template: Source-to-target field mapping (to be filled when integration is defined).

Source System	Source Entity.Field	Target Entity.Field	Transform/Rule	Validation
AIDA-PCE	prf_movimentos.codigo	stock_movements.article_code	Normalize code (upper)	Must exist in
AIDA-PCE	prf_movimentos.data	stock_movements.event_ts	TZ-aware convert	Not null
AIDA-PCE	prf_movimentos.utilizador	audit.actor	Map to role/user id	Exists in use

All entries must be derived from institutional documentation and/or tmp_ai_reports summaries, with full anonymization and without inserting record-level data.

A.6 Reference Backlog (to be populated)

This backlog lists references to be added/confirmed (e.g., national guidance, related implementations). Each entry should capture citation key, short note, and target chapter/section.

- SNS/SPMS guidance on interoperability/security: target State of the Art (Section 2.2.6).
- Case studies of unified front-ends over legacy HIS: target State of the Art (Related Implementations).
- eMAR/BCMA implementation reports in similar contexts: target State of the Art (Section 2.2.3).
- ROI unit cost sources for ADE and time-savings: target Contribution (Financial Impact).

Appendix B
Details of Results

This appendix consolidates evidence and materials referenced throughout the dissertation that would otherwise disrupt the flow if included inline. It also provides a practical roadmap for inserting new evidence as it becomes available, aligned with the improvement analysis (docs/ and tmp_ai_reports/).

B.1 Roadmap for Evidence Insertion

The following items specify where to place each type of evidence when ready. Each item cites the target chapter/section and recommended figure/table label.

- As-is architecture diagram (SCMVV): Introduction (Section 1.4); Figure label `fig:as_is_architecture_scmvv`.
- Current medication process swimlane: Introduction (Section 1.5); Figure label `fig:as_is_swimlane_scmvv`.
- Baseline artefacts (legacy screens, anonymized extracts): Results (Baseline sections), with table/-figure labels `fig:baseline_*` or `tab:baseline_*`.
- Qualitative before/after comparison table: Results (Table 2); update cells with evidence.
- Performance snapshots (API latencies, reliability): Results (Indicative Performance), figures `fig:perf_*`.
- User acceptance artifacts (SUS summary, interview quotes): Results (Stakeholder Feedback), tables/figures `tab:sus_*`, `fig:feedback_*`.
- ROI/Cost elements (if applicable): Expected Results (Financial Impact), Figure 10 notes.

B.2 Evidence Checklist (docs/ and tmp_ai_reports/)

To ensure coverage without overclaiming, collect the following (no counts here):

- Representative legacy process artifacts: prescription, validation, administration records; stock movement entries (fields only).

- Screenshots/mockups: legacy AIDA-PCE views relevant to the cycle; new unified screens for the same steps.
- Workflow timing anchors: available timestamps at order entry, validation, dispensing, administration.
- Handoff indicators: examples of pharmacist-prescriber clarifications; typical turnaround points.
- Data coherence samples across systems: patient IDs, active medication lists, stock positions, highlighting discrepancies.
- Usability notes linked to specific screens: navigation friction, duplicate entry, missing alerts.

B.3 Notes on Anonymization and Compliance

All artifacts inserted must be anonymized and comply with GDPR and institutional policies. Where real screenshots cannot be shown, use faithful mockups and describe the original fields/flows.

B.4 Outstanding Improvements (from docs/ and tmp_ai_reports/)

This section centralizes planned improvements identified in the analysis. Each item notes the target chapter/section and what will be inserted (no content invented here; placeholders remain until evidence is available).

- ROI model details (Contribution, Financial Impact): specify inputs/assumptions (development/-maintenance costs, avoided ADE costs, time savings, licensing deltas), method notes, and sensitivity analysis plan. Link to Figure 10.
- eMAR/BCMA alignment (State of the Art, Section 2.2.3; Methodology/Contribution): add bedside administration flow alignment notes; produce mockups if actual screens unavailable.
- National context references (State of the Art, Section 2.2.6): add 1–2 references to SNS/SPMS guidance or reports, once confirmed.
- Related implementations (State of the Art): add short paragraph citing case studies of unified front-ends over legacy systems, if identified.
- KPI operational definitions (Contribution, Section 5.6.1): define error categories, cycle-time measurement points, adoption and reliability indicators (definitions only).

- Security/compliance evidence (Results, Security and Compliance Posture): add configuration snippets and process notes (authN/authZ, encryption, audit), and ethics approval metadata (identifier/-date) when available.
- Screenshots/mockups per step (Results): legacy vs. new for prescription, validation, administration; ensure captions include source and anonymization notes.
- Baseline anonymized extracts (Results): controlled-substance movement fields, sample record structures; no counts included.

B.5 Cross-reference and Labels Validation Checklist

Before final compilation, confirm the following labels and references resolve correctly and point to the intended figures/tables/sections.

- Introduction: `fig:as_is_architecture_scmvv`, `fig:as_is_swimlane_scmvv`; Sections 1.3, 1.4, 1.5.
- State of the Art: Sections 2.2.3, 2.2.4, 2.2.6.
- Contribution (Expected Results): Figure 7, Figure 10, Figure 11; Section 5.6.1.
- Results: Table 2; baseline sections and appendix reference B.
- Discussion: references to as-is baseline (Sections 1.4, 1.5).

B.6 Mock Artifact Production Guidance

When real evidence is not available, produce mockups with the following constraints:

- Faithfully reflect fields and flows described in docs/ and tmp_ai_reports/; avoid introducing features not mentioned.
- Include caption notes with source ("consolidated from docs/tmp_ai_reports") and a disclosure that the image is a mockup.
- Store images under `images/generated/` and replace placeholders when real artifacts become available.

Appendix C
Listings

Should this be the case.

Appendix D
Tooling

(Should this be the case)

Anyone using LaTeX should consider having a look at TUG , the TeX Users Group .

Place here information about funding, FCT project, etc. in which the work is framed. Leave empty otherwise.