

HARMONY

(Healthcare, Administration & Research Managed On a New Blockchain Yield)



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Certificate

We do hereby verify the work in the report entitled HARMONY: Healthcare, Administration & Research Managed On a New Blockchain Yield, written by Mr. Abdul Sami bin Anwar and Mr. Muhammad Daud, as an attestation of the necessary standard of the partial completion of the degree, Bachelor of Science in Computer Science.

The present project demonstrates the successful integration of three interdependent modules can be brought together: Hospital Desktop Application with patient management, Researcher Platform Web Portal with medical research collaboration, and Authority Platform Web Portal with health administration and policy making of the government, all interconnected within the HARMONY ecosystem.

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Abstract

Healthcare systems worldwide face persistent challenges in managing sensitive health data, including fragmented silos, limited interoperability, and ongoing security and privacy risks that impede clinical care, research collaboration, and public health governance. Although early blockchain pilots improved auditability and data provenance, they rarely connected hospital workflows, researcher platforms, and authority surveillance into a single, privacy-preserving ecosystem capable of end-to-end, compliant data sharing.

This report addresses the problem of securely managing and exchanging healthcare data across hospitals, researchers, and government authorities while guaranteeing integrity through immutability, enforcing strict role-based access control, preserving patient privacy via anonymization for secondary use, enabling real-time collaboration.

To solve this, we present HARMONY, an integrated and modular healthcare data ecosystem. The Healthcare Application supports clinical operations with encrypted storage, role-based access, and immutable audit trails using Hyperledger Fabric. The Researcher Platform enables secure research publication and discovery, anonymized data access, study rooms with real-time messaging, and AI-assisted analysis powered by Groq and HuggingFace over Supabase PostgreSQL and Storage. The Authority Platform provides authenticated statistics management, real-time disease surveillance, and blockchain-backed population health analytics. The architecture uses privacy-by-design, JWT and RBAC, time-bound signed URLs, Zod validation, and standardized APIs to unify the modules while maintaining compliance and comprehensive auditability.

Implementation results across all three modules demonstrate secure authentication and fine-grained authorization, tamper-evident recordkeeping, AI-supported research summarization and insights, and integrated analytics dashboards for disease trends and health statistics. Testing and validation reported complete coverage of core workflows. The system achieved seamless cross-module data flow with preserved privacy, improved researcher productivity through AI tools, and enhanced authority visibility into real-time population health indicators. These findings support the feasibility of a unified ecosystem that advances clinical care, accelerates research, and strengthens public health governance.

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ABDUL SAMI BIN ANWAR & MUHAMMAD DAUD

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“We think someone else, someone smarter than us, someone more capable, someone with more resources will solve that problem. But there isn’t anyone else.”

Regina Dugan

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Chapter 1

Introduction

1.1 Project Overview

The data management and security are now the fundamental issues of concern in the fast-changing sphere of healthcare. Healthcare providers receive, process and store enormous volumes of patient data, such as medical histories, diagnoses, treatments and personal data. Although these records are important, the traditional patient management systems tend to be having issues with data security, integrity and interoperability. Medical data sharing and unauthorized access, data breaches, and inefficiencies are widespread problems that have a direct effect on patient care, privacy, and overall health management.

HARMONY: Healthcare, Administration & Research Managed On a New Blockchain Yield is one of the solutions to overcome these issues. Using the blockchain technology, HARMONY offers a transparent, secure, and decentralized platform of managing patients. The nature of blockchain of immutability, transparency and the decentralization controls makes patient data remain safe, traceable and cannot be altered unlawfully. HARMONY reinvents the model of managing, accessing, and sharing patient data across health institutions by eliminating the conventional centralized system of storage and adopting a blockchain based system.

HARMONY has three major stakeholders, including hospitals, patients, researchers and government health authorities. Patients records can be stored and shared safely and only accessed by the authorized personnel in the hospitals. Improved privacy, automatic delivery of test result and reports, and the ability to control their data, increase benefits to patients. Academic research results benefit the researchers by providing them with anonymized patient data allowing them to advance medicine without interfering with patient privacy. Real time blockchain allows government health authorities to track the health trends of its population, analyze disease trends, manage statistical reports, and coordinate

responses in the area of population health analytics and team solutions powered.

The HARMONY ecosystem consists of 3 modules which are linked and are used in harmony to come up with a holistic healthcare data management and governance solution. The **Healthcare Application** is a patient management system that is secure desktop-based and is used in hospitals to achieve effective clinical operations and patient care. The **Researcher Platform** is a cooperative web based platform where medical researchers and students can find out anonymized data, present research results and engage in scholarly discussions. The **Authority Platform** enables government health authorities to have the sophisticated analytics, statistical report management, and population health surveillance functions with the usage of blockchains. This three module model is important in that clinical information that is obtained in hospitals can be employed ethically in the process of enhancing medical research and in offering authorities with a holistic understanding of the population health in order to inform policy making and administration of health to the populace.

1.2 Problem Description

There are also some longstanding challenges in the healthcare system of managing patient data across the world:

- **Data Security Risks:** The conventional system stores patient records in databases that are centralized and are therefore susceptible to data invasion, insider intrusion, and data attacks.
- **Data Integrity Issues:** Records that are administrated manually are prone to manipulation without authorization hence providing misleading or wrong information.
- **Ineffective Data Sharing:** Hospitals and medical professionals have difficulties with sharing patient data in a safe and secure way, which leads to disjointed medical records and delayed treatment.
- **Lack of Control by the patients themselves:** patients do not always have the visibility and control of their health data, and they are uneasy about who may access their records.
- **Limited Access to Researchers:** This type of privacy does not allow access to valuable patient data by researchers and hence limits medical research and innovation.
- **Fragmented Research Collaboration:** Medical researchers usually operate in solitude without having a platform to share, analyze, and exchange knowledge in a safe environment.
- **Inefficient Research Workflows:** The researchers have a hard time with old uploading, discovery, and analysis systems of medical research, which impedes the development of science.

- **Poor AI adoption:** Health institutions and research organizations do not have complex AI-based applications to analyse data, identify patterns and predictive healthcare implications.
- **Poor Health Surveillance:** Governmental authorities do not have access to real time data on population health and this makes it difficult to keep track of disease trends and the ability to organize population health actions.
- **Disconnected Health Governance:** The lack of integration between clinical practices, research practices, and government health surveillance creates a loophole in health overall management and policy making.

These issues undermine patient privacy, undermine collaboration in research, effectively do population health surveillance and constrain authorities to make data informed public health decisions. HARMONY tackles all these directly by relying on blockchain technology to guarantee data protection, integrity, and transparency and offer a complete suite of clinical functionality, medical research development, and government health management.

1.3 Project Objectives

HARMONY will have the following major objectives:

- **Secure and Immutable Data storage:** Patient records are stored in a blockchain and thus are tamper proof and traceable.
- **Role Based Access Control:** Use an access control mechanism that will not allow unauthorized persons to access or alter patient records.
- **Protection of Patient Privacy:** Public data anonymity of patients, but provide full information to authorized individuals.
- **Automated Patient Notifications:** Send real time notifications to the patients about diagnoses, test results, and medical reports.
- **Researcher Access to Anonymized Data:** Provide access to anonymized patient data to researchers so that they can study and analyze it.
- **Collaborative Research Environment:** Empower researchers to upload, share and find medical research articles with state-of-the-art search and filtering options.
- **AI-Enhanced Research Analysis:** Add artificial intelligence solutions to summarize the research, analyze patterns, and make recommendations.
- **Real time Research Collaboration:** Provide study rooms and messaging systems to enable the researcher to collaborate and share insight on projects.

- **Advanced Analytics and Reporting:** Produce advanced statistical health reports and population health analytics that can be used by authorities to track the trends in the public health.
- **Government Health Surveillance:** Empower the government to monitor disease trends, health crises, and organize the response of the populace to health issues.
- **Analytics on the Blockchain:** Adopt secure blockchain analytics in health statistics management and population health surveillance.
- **Statistical Reporting to Authorities:** Generate statistical health reports to authorities to watch the trends in public health.
- **Smart Data Exchange across Hospitals:** Seamlessly exchange patient records with a secure and real time exchange of patient data between involved healthcare institutions.
- **Enhanced Data Integrity:** Be sure that patient records cannot be manipulated because of the impeccability of blockchain.

1.4 Project Scope

HARMONY has the following areas:

1.4.1 Healthcare Application Module

- Creation of a blockchain based patient management system in the form of a desktop application.
- Role based access control among the hospital personnel, where the permissions are granted on the basis of the roles (e.g., doctors, nurses, administrative staff).
- Blockchain-based secure and encrypted storage of patient records.
- Patient notification System, auto-updates on diagnoses, test results and reports.
- Artificial intelligence features of predictive analysis to support doctors in diagnosis and authorities in trend analysis.
- Authentication and access control in order to avoid illegal access to confidential information.

1.4.2 Researcher Platform Module

- Creation of an elaborate web based research collaboration platform.
- Protect user authentication and profile management of researchers and students.

- Advanced metadata support Research paper upload, management and sharing system.
- High-level search and discovery tools using tag, author, institution, and research area search.
- Intelligent research assistant: Artificial intelligence (AI) based on the analysis, summarization, and intelligent suggestions of documents.
- Live research and project coordination study rooms.
- Commenting and peer review systems on academic discourse and sharing of knowledge.
- Data access by researchers (anonymized), allowing medical studies without interfering with patient privacy.
- Population health insights and research trend analysis analytics dashboard.
- Medical data was secured by being integrated to blockchain and used in research.

1.4.3 Authority Platform Module

- Establishment of an all-inclusive government health authoritative platform of population health management.
- Secure authentication and role based access control of government health officials and administrators.
- Disease surveillance and real time population health monitoring dashboard at advanced analytics.
- Health data analysis and policy making statistical report generation and management system.
- Introduction of blockchain into health data analytics and trend analysis.
- Pattern monitoring and early warning of disease outbreak and management of a public health crisis.
- Visualization programs of overall health statistics and demographic analysis.
- Public health emergency response management tools: secure communication and coordination.
- Hospital and research data integration to provide insights in population health.
- Government standards of data protection and health information security.

1.4.4 Integrated System Features

- Creation of statistical reports to health authorities enabling them to monitor disease prevalence, patient population and health trends in the population.
- Harmonious exchange of data between the hospital operations and research activities and government health surveillance without undermining privacy.
- Powered by blockchain analytics between clinical data, research, and population health.
- Adherence and data protection and privacy regulations (GDPR, HIPAA) in all three modules.
- Multi-platform cross platform compatibility and responsiveness to different devices and screen sizes.
- Full audit trails and documentation of all system activities on healthcare, research and authority systems.
- Immediate information synchronisation and safe communication among hospitals, researchers and government authorities.

HARMONY is created to support hospitals, research settings, and government health departments and supports them with a secure, scalable, and user friendly solution to their multi-faceted healthcare data management, research collaborations and populational health governance.

1.5 The Degree Project Report

Project report is an essential part of the final year project of the Bachelor of Science in Computer Science. This is designed in such a way as to give a detailed and internally consistent description of the project that is entitled: "HARMONY: Healthcare, Administration & Research Managed On a New Blockchain Yield." The report has been divided into various chapters which cover a particular area of the project such as background, objectives, design, implementation, testing, and conclusions.

This is progressive line of development that is consistent with an ordinary Implementation Plan of a project. The report is logically and methodically organized since it begins with the identification of the problem and literature review and then continues to the design of the system, implementation, and testing. This will make the scope of the project, technicalities, and results easy to understand by the reader.

The aim of the HARMONY project is to develop better management of health-care data by applying blockchain technology that will guarantee efficient, tamper proof, and secure management of patient data. With the integrated ecosystem,

the Healthcare Application, Researcher Platform, and Authority Platform constitute the clinical operation, medical research development, and population health governance respectively. All sections of this report give comprehensive perspectives of the system architecture, functionality, and performance in accordance with the industry best practices of developing a secure and scalable software.

Effective communication requires a well structured and consistently formatted project report and can be attributed to a professional style of project management. Precision, summariness, and rational arrangement have been given priority in this paper; hence the material is made easy to read by the technical and non technical audience.

The following is a full authoritative document of the HARMONY project, which will be a record of the project objectives, design, implementation, testing as well as future scope of the Healthcare Application, Researcher Platform and Authority Platform modules.

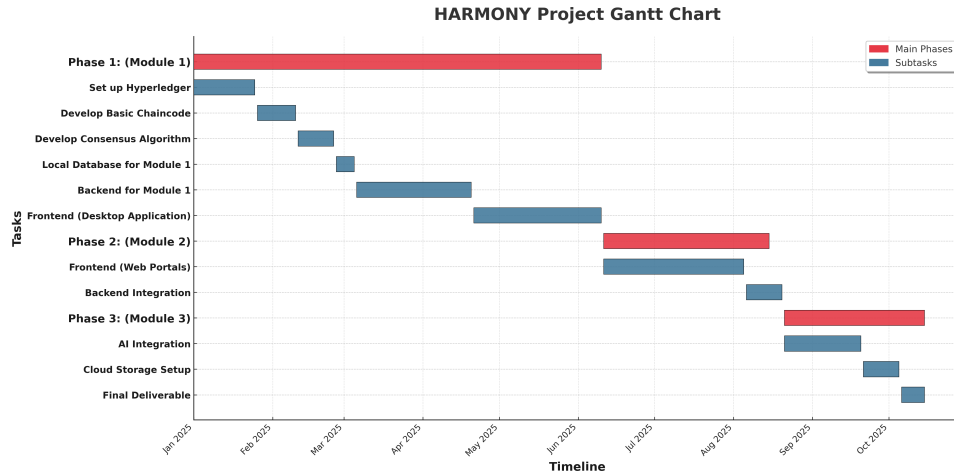


Figure 1.1: Final Year Project Implementation Plan

Chapter 2

Literature Review

2.1 Overview of Decentralized Ledger Technologies in Modern Healthcare Data Ecosystems

The blockchain technology has become a revolutionary technology in healthcare as it is a decentralized, immutable registry that is expected to eliminate some of the decades old problems of integrity of data, interoperability, and security. Initial projects, including MedRec [1] and HealthChain, had shown how distributed consensus mechanisms could substitute the vulnerable centralized databases, to achieve tamper resistant audit trails of patient records and to mitigate single points of failure. These pilot systems highlighted the possibility of permissioned networks in which only approved entities are involved to strike a balance between transparency and confidentiality so that hospitals are able to disclose data without exposing sensitive information to unauthorized individuals. Nevertheless, scalability and compatibility with the current electronic health records (EHR) systems constitute key aspects to be optimized to achieve widespread clinical implementation.

2.2 Ensuring Data Integrity and Patient Privacy through Blockchain Encryption and Anonymity Mechanisms

Research within the recent five years [4] has been keen on ensuring patient privacy on blockchain based healthcare systems. Methods, including cryptographic hashing, zero-knowledge proofs, and off chain storage of weighty medical data have been suggested to avert unauthorized access, and assure that delicate information never gets on-chain in any form. The use of attribute based encryption schemes [6] can provide fine grained control over people who are permitted

to decrypt certain portions of a patients record, and pseudonymization and dynamic identity management systems keep privacy by not identifying real life identities on chain transactions. These developments underscore the difficulty of maintaining verifiable data provenance and maintaining strict confidentiality standards required by laws like GDPR and HIPAA.

2.3 Implementing Role Based Access Control and Permissioned Networks for Secure Clinical Environments

Multi stakeholder healthcare systems cannot be achieved without a strong access control. Literature also indicates that auditing properties of blockchain combined with role based access control (RBAC) models can improve both the operational efficiency and security. In approved blockchain models such as Hyperledger Fabric, access rules are programmed in smart contracts, which automatically perform authentication and authorization to the various user categories such as physicians and nurses to laboratory technicians and administrative personnel. Empirical assessments have shown that there have been serious decreases in unauthorized access attempts, and more detailed and immutable log records that are useful in compliance auditing and forensic investigation in case of data breaches.

2.4 Leveraging Blockchain for Collaborative Medical Research and Anonymized Data Sharing

Scholars have investigated the potential of blockchain to support mass, anonymized data sharing across institutions and support clinical research and maintain patient confidentiality. Decentralized networks of data markets and consortium networks offer access to aggregated datasets under controlled access to collaborate on disease modeling, drug discovery and epidemiological tasks. Smart contract based data exchange protocols allow consenting patients to either give or withhold data on-the-fly, empowering individuals and increasing research possibilities. Nonetheless, there are still difficulties in standardizing data formats, harmonizing ontologies, and consent workflow management within a blockchain environment, though it could lead to improvement.

2.5 Digital Research Collaboration Platforms and Knowledge Sharing Systems

The evolution of digital research collaboration has revolutionized the knowledge sharing among medical professionals and collaborative research. The current research platforms take advantage of cloud computing, instant collaboration platforms, and sophisticated search tools to help in networking researchers around the world [9]. Research has demonstrated that the digital research setting enables the scientific discovery process to become much faster due to instant access to research papers and peer review processes, as well as through collaborative analysis [10].

Modern research sites combine various forms of communication, such as study rooms in which people can have intense discussions, comment boards where people can receive feedback, and messaging features that allow direct cooperation. These platforms have played a crucial role when the world is facing a global health crisis because they allow quick knowledge sharing and development of response [11]. Artificial intelligence has also been applied in research platforms to position them as more useful in terms of automated literature review, intelligent research recommendations, and pattern recognition of large datasets.

The digital research collaboration has some of the following challenges such as data security, the integrity of a research, and intellectual property management. New advances on blockchain secured research platforms have largely resolved these issues by offering publication records that are immutable, transparent peer review systems, and secure attribution systems [12].

2.6 Government Health Information Systems and Population Health Surveillance

There has been an increasing trend in the use of sophisticated information systems by the government health authorities across the world in terms of population health surveillance and policy formulation. Such systems combine information across various sources hospitals, research centers and community health agencies in an effort to obtain a holistic view of the health trends of the population as well as trends in disease [14].

The use of modern government health platforms powered by sophisticated analytics is creating the opportunity to monitor diseases in real-time to provide early warning of an outbreak and coordinate a quick response. The COVID-19 pandemic has outlined the importance of having an integrated health surveillance system as real-time information exchange between hospitals and health authorities proved to be extremely important to enhance the efficacy of emergency responses [15].

The blockchain technology has become a useful asset in the case of govern-

ment health systems, offering secure auditable records of management of health statistics. Health surveillance systems based on blockchain provide a higher level of data integrity, better inter-agency cooperation, and open reporting functions with anonymization of patient data, provided by advanced methods of anonymization [16].

Another important part of government health systems is the management of statistical reports. It has been reported in literature that automated statistical analysis and reporting are important in enhancing speed and accuracy in decision making during the development of policy of public health [17]. Combination with hospital management systems and research platforms allows an in-depth analysis of population health, informing the process of policy development and resource allocation.

2.7 Integrating Artificial Intelligence with Blockchain-Enabled Patient Management for Predictive Healthcare Insights

The intersection of AI and blockchain offer new directions of improving the accuracy of the diagnosis and operational planning. Literature describes architectures in which machine learning models can query encrypted patient data stored on chain or in secure off chain repositories to make real time predictive analytics on disease progression, resource allocation, and individual treatment recommendation. Blockchain guarantees integrity and auditing of the training data and inference logs, and alleviates threats of multi modal brain image analysis, automated research summarization, and smart prescription systems to medical literature discovery.

Research assistance has been transformed by AI, which is now used to search and analyze scientific publications by medical professionals. Modern systems use natural language processing to give automatic research summary, research gaps and propose a relevant study using user interests and research history [18]. These systems save a lot of time in which the literature can be reviewed and also allow the researcher to keep up to date with the fast changing body of medical knowledge.

AI can be used to improve population health analytics in government health applications to identify patterns of particular diseases, forecasting the possibility of an outbreak, and allocating resources more effectively. Certain population health trends that would have otherwise been difficult to identify through traditional statistical methods can be identified through machine learning algorithms of blockchain secured health data [19].

The adoption of AI within the hospital, research and government health platforms brings about prospects of having all-inclusive healthcare intelligence systems. The federated learning methods allow federating AI models to be trained on

multiple institutions without necessarily sharing sensitive information, allowing collaborative AI development without breaching privacy and security considerations [20].

2.8 Multi Platform Healthcare Ecosystems and Interoperability

Recent studies have highlighted the need to have integrated healthcare ecosystems which are integrated to dock clinical operations, research activities, and government health surveillance. Such multi platform strategies allow managing the entire lifecycle of data, starting with patient care up to the use of research in creating the population health policy [21].

The exchange of data between two or more healthcare platforms using interoperability standards like FHIR (Fast Healthcare Interoperability Resources) and HL7 has supported the security and privacy needs. Research has shown that healthcare ecosystems that are well integrated will greatly enhance patient outcomes, medical research, and the overall health response capabilities of the population [22].

Multi platform healthcare ecosystems based on blockchain technology are a common infrastructure that ensures security, integrity of data, and audit features across all hospital management systems, research environments, and government health surveillance surveillance tools. The integrated strategy allows safe information exchange and at the same time restricts access according to the needs of the particular platform.

2.9 Comparative Analysis

Major applications like MedRec [1], FHIRChain [2], and the associated frameworks include [4, 6, 7] provide essential insights on comparative analysis as well as future system development. The table below illustrates a detailed comparison of the conventional healthcare systems, current blockchain based solutions and the proposed HARMONY framework in all three modules.

Table 2.1: Comparative Analysis of Traditional Systems, Existing Solutions, and HARMONY Ecosystem

Feature	Traditional Systems	Existing Blockchain Solutions	HARMONY
Hospital Management	Oracle Health Database [3], Epic Systems [8]	MedRec (MIT) [1], BurstIQ [5], MedicalChain	Desktop Application with Hyperledger Fabric
Research Platforms	Traditional institutional repositories [10], ResearchGate	Limited blockchain integration [12], mostly centralized	Web based platform with AI integration and blockchain security
Government Systems	Centralized health databases [14, 15], manual reporting	Pilot projects with limited integration [16]	Blockchain analytics with real time surveillance
Data Storage	Centralized databases with silos	Decentralized but often fragmented	Unified blockchain with module specific access
Data Ownership	Institution controlled	Partially decentralized	Patient controlled with institutional governance
Security	Vulnerable to centralized attacks	Improved but implementation dependent	End to end encryption across all modules
Privacy	Basic encryption, data leak risks	Variable privacy implementations	Advanced anonymization with blockchain integrity
Interoperability	Limited cross system sharing	API based with security concerns	Seamless blockchain secured data flow
Research Collaboration	Manual processes, email based	Limited real time collaboration	AI powered research assistance and study rooms
Government Integration	Slow manual reporting cycles	Minimal government platform integration	Real time analytics and automated reporting
AI Integration	Separate AI systems	Limited or no AI integration	Comprehensive AI across all modules
Data Modification	Admin controlled edits/deletes	Variable immutability enforcement	Immutable ledger with controlled updates
Multi Stakeholder Support	Single purpose systems	Limited multi stakeholder design	Integrated ecosystem for hospitals, researchers, authorities

Feature	Traditional Systems	Existing Blockchain Solutions	HARMONY
Scalability	Institution specific scaling	Network dependent performance	Modular scaling with Hyperledger Fabric
Compliance	Custom implementations	Variable regulatory compliance	HIPAA/GDPR compliant by design
Cost Effectiveness	High maintenance and licensing	Variable costs, often high	Reduced intermediary costs, open source foundation
Real time Capabilities	Limited real time features	Depends on blockchain type	Real time notifications and collaboration across modules

2.10 Identified Gaps and Motivation for HARMONY

The current systems notwithstanding the promising prototypes along with evidence of concept deployments, do not always integrate seamlessly all important elements of the secure data storage, fine grained access control, research grade anonymization, government health tracking, and AI driven decision support in a whole eco system. The existing technological environments of healthcare service providers experience the following critical drawbacks:

Lack of Integration of healthcare data management: The current systems are mostly not integrated, which forms a data silo among hospitals, research centers, and government health agencies. This division hinders the ability to conduct a thorough analysis of population health and reduce the possibility of joint medical progress.

Little Research Clinical Integration: Unlike during the time of manual processing, traditional systems provide little or no integration between clinical and research operations and the process of data extraction and anonymization is time consuming and error prone.

Weak Government Health Surveillance: The current government health systems usually take advantage of delayed, manual reporting by the healthcare institutions hence limiting their capability to monitor the emerging health trends, or respond swiftly to health crises.

Lack of AI Integration: Although there are individual AI-based tools in the healthcare, few solutions can be found to offer an integrated AI across clinical, research, and governance processes within a single platform.

Security and Privacy Issues: Current platforms are grappling with the dilemma of accessibility of data to researchers and governance and strong privacy demands that in most cases lead to highly restrictive systems that restrict valid data utilization.

Lack of Good Collaborative Research Support: The conventional research platforms do not have advanced collaboration methods, real time communication, and AI assisted research discovery tools that are required in contemporary medical research.

HARMONY would fill such gaps by providing an inclusive, blockchain secured platform where hospital management, research partnership, and government health surveillance are interconnected in a single platform. The system provides:

- **Unified data architecture:** Blockchain based data management ensures that there is uniform security and integrity of all modules and that various stakeholders are allowed access to the data according to their needs.
- **Fluent Multi Platform Integration:** Real time data exchange between the hospital operations, research and government surveillance without compromising privacy and security requirements.
- **Intense AI Ecosystem:** Full-fleet AI capabilities of clinical decision support, research support, and population health analytics on one ecosystem.
- **Collaborative Research Environment:** The state-of-the-art research platform including study rooms, AI-based literature analysis, and real time collaboration solutions to support the development of medical research around the world.
- **Real time Government Analytics:** Existing Government Surveillance based on blockchain to support real time trend detection, automated statistical reporting and coordinated public health response capabilities.
- **Modular, Scalable Architecture:** Open-source low-implementation, low-maintenance architecture, based on high-scalable, modular architecture compared to traditional enterprise healthcare systems.

HARMONY ecosystem is a paradigm shift of fragmented, single purpose healthcare systems to an integrated, intelligent platform that supports the entire healthcare data lifecycle, including patient care all the way up to research advancement and population health governance.

Chapter 3

Requirement Specifications

3.1 Existing System

3.1.1 Centralized Database/Cloud Based EHR Platforms

- **Epic Systems:** A popular cloud based EHR system which has integrated patient profiles and clinical workflow. It is however dependent on centralized servers and this causes single points of failure and high chances of data breach in large scale cyberattacks. HL7 interfaces and custom middleware can also be expensive to interoperate with different hospital networks.
- **Cerner Millennium:** It is a strong platform with patient management and coordination, albeit with a monolithic architecture that does not promote real time data sharing between institutions. The performance bottlenecks are at peak loads and local workflow customization may take long vendor engagement, increasing the cost of operation.

3.1.2 Traditional Research Collaboration Systems

- **ResearchGate:** This is a social networking site for researchers which allows them to share and collaborate in research. In as much as it helps in academic networking, it does not have secure data handling processes of sensitive medical research and neither can it offer real time collaboration features or AI enabled analysis features.
- **Institutional Repositories:** Traditional academic repository systems such as DSpace and EPrints allow the storage and discovery of research, but do not have cross-institutional collaboration functionality, advanced search, or integrated communications.
- **PubMed Central:** A biomedical literature database that is comprehensive and is published by the PubMed is an efficient tool of research discovery

but does not offer collaborative functions, discussion in real time, and personalized research recommendation systems.

3.1.3 Government Health Information Systems

- **CDC WONDER:** CDC WONDER is an online database system of Centers for Disease Control and Prevention where public health data is to be found, but which is based on batch processing with a lot of reporting delays and shorter real time surveillance.
- **WHO Health Observatory:** International health surveillance system which consolidates the health data of member states but has flaws in the consistency of data, reporting lag and analysis of health data in real time interpretation.
- **National Health Surveillance Systems:** Country specific systems such as England NHS Digital and Canada CIHI offer population health surveillance but on a small scale with little international data sharing and co-ordination capacity.

3.1.4 Blockchain Inspired Prototypes

- **MedRec (MIT):** A prototype medical record provenance permissioned blockchain. Although it illustrated unalterable audit records and patient centered consent monitoring, the system had a weakness of poor scalability and failure to integrate with off chain imaging and big diagnostic records.
- **FHIRChain (Duke University):** The FHIRChain used smart contracts to connect the disparate clinical systems through the FHIR standard [2]. Despite enhancing interoperability at a proof of concept level, the dependency on shared testnets added latency and transaction costs which made it impossible to deploy in practice.

3.1.5 Other Notable Implementations

- **HealthChain:** This is a type of blockchain hybrid architecture that combines on chain metadata and off chain storage of large datasets. Although such a balanced design, it needed ad hoc synchronization, which is expensive to maintain and fault diagnostics.
- **Guardtime KSI:** National health record verification has been applied using hashchain technology. Being very secure and scaleable, it still suffered the proprietary nature, which introduced vendor lock in and reduced the ability to add new modules or integrate AI.

3.2 Proposed System

HARMONY proposes a blockchain architecture that is highly integrated and holistic and integrates healthcare data management in three essential areas: hospital operations, medical research collaboration, and government health surveillance. This new ecosystem breaks down the shortcomings of centralized and experimental blockchain solutions by offering an interconnected ecosystem that serves hospitals, researchers, and health authorities in one, safe infrastructure.

3.2.1 Healthcare Application Module

The hospital management aspect utilizes a permissioned ledger architecture that supports clinical settings and that all transactions are recorded on an immutable basis as only authorized participants are involved in consensus. This architecture removes the unprotected points within the system and prevents unwarranted data leakages. Data storage, integrates on chain metadata with off chain repositories which are encrypted and can store large diagnostic files without hurting performance. The modular nature allows the hospitals to install lightweight nodes in every department, which promotes near real time interoperability, without the need to rely on external networks.

3.2.2 Researcher Platform Module

The research collaboration platform offers a secure web based platform on which medical researchers and students can access anonymized patient data, upload and share research results and engage in real time collaborative discussions. The platform combines AI-driven research analysis features, advanced search features, and study rooms to collaborate with their studies in a focused manner. Introducing blockchain will guarantee that the research is trustworthy and has records that can be audited to be published with appropriately high privacy safeguarding of sensitive medical information.

3.2.3 Authority Platform Module

The government health surveillance aspect grants the health authorities the population health monitoring and analytics services. This module will offer real time disease surveillance, trend informatics of statistical reports and blockchain enabled analytics to support the trend detection and policy decision making. The site facilitates safe data exchange amongst government departments and healthcare organizations and supports privacy and regulatory standards.

3.2.4 Integrated Ecosystem Benefits

Access control across all modules is controlled by dynamic, role based policies built in templates of smart contracts and can be adapted by administrators without code modifications. This solution provides a fine grained governance

maintains patient records, research data, and statistical reports and maintains conformance with regulatory requirements and auditability.

The single platform unites clinical care, medical research, and governance of the public health by using pluggable AI modules which can be added at any point of the workflow. Training and predictive analytics operate on chain federated, secure data pools, and the traceability of training and inference logs is complete. This design will enable the future growth to highly advanced decision support tools without re-engineering the basic system.

HARMONY in general consolidates patient management, collaborative research, and health governance on a single, extensible platform, to deal with scalability, privacy, and usability issues of current systems without losing a future proof architecture as healthcare needs evolve.

3.3 Requirement Specifications

The HARMONY system is intended to transform healthcare data management in a secure, blockchain based platform that guarantees data integrity, privacy and smooth interoperability of hospital operations, medical research, and government health surveillance. The comprehensive requirements are module oriented to show the specialization needs of each component but is system wide to ensure that the requirements are consistent across the system.

The Healthcare Application module meets the vital requirements of hospital settings and has extensive functionality on all hospital administrators, physicians, nurses, and pharmacists in terms of user authentication, patient records, prescription and vital signs monitoring. Researcher Platform module is based on collaborative research features as secure research sharing, AI powered analysis, real time communication, and advanced analytics. The Authority Platform module enables the governmental health agencies to have sophisticated surveillance solutions, statistical report management, and population health analytics that are operated on blockchain.

Non functional requirements are critical cross cut issues that are covered like performance optimization, security implementation, regulatory compliance and scalability to meet multi institutional deployments. With the reliance of Hyperledger Fabric as the tool to provide immutable record keeping and the full-fledged role based access control, the HARMONY will offer the solid system of the safe data sharing in addition to the possibility to share research anonymously and monitor health in real time.

The specified specifications guarantee the system complies with the standards of the healthcare industry but consider usability, auditability, and compliance with regulations in all three modules.

3.3.1 Functional Requirements

3.3.1.1 Healthcare Application Module Requirements

Table 3.1: Healthcare Application Module Functional Requirements

Req. No.	Requirement Name	Requirement Description	Status
FR1	Admin Dash-board	Provides administrators with system overview and management tools	Completed
FR2	Employee Man-agement	Allows admin to manage staff profiles and access permissions	Completed
FR3	System Activity Monitoring	Tracks and displays user actions and system events for auditing	Completed
FR4	Doctor Patient Management	Enables doctors to access and update patient medical records	Completed
FR5	Medical Record Creation	Allows creation of new patient examination records with diagnoses	Completed
FR6	Nurse Patient Registration	Provides tools for nurses to register new patients	Completed
FR7	Vital Signs Man-agement	Enables recording and tracking of patient vital measurements	Completed
FR8	Prescription Pro-cessing	Allows pharmacists to manage medication prescriptions	Completed
FR9	Data Encryption System	Secures sensitive patient data through encryption	Completed
FR10	Blockchain Data Storage	Stores and retrieves patient records on distributed ledger	Completed
FR11	Role Based Ac-cess Control	Restricts system access based on user roles	Completed
FR12	Secure Session	Manages authenticated user sessions securely	Completed
FR13	Report Genera-tion	Produces printable medical documents	Completed
FR14	Audit Trail Sys-tem	Maintains immutable logs of critical system actions	Completed

3.3.1.2 Researcher Platform Module Requirements

Table 3.2: Researcher Platform Module Functional Requirements

Req. No.	Requirement Name	Requirement Description	Status
FR-01	User Authentication	Email/password authentication using Supabase, on Sign Up the system sends an email verification link, and only verified accounts can Login, supports session creation, restore, and logout	Completed
FR-02	User Profiles	Create and update own profile (name, bio, preferences) with optional avatar upload to Supabase Storage	Completed
FR-03	Research Upload	Authenticated user uploads their research files with metadata, server issues signed upload URLs and persists records	Completed
FR-04	Search	Search and browse public research with filters and sorting from server endpoints	Completed
FR-05	Research Detail	View research details and securely download artifacts via time bound signed URLs	Completed
FR-06	Comments	Create, list, and delete comments on research posts with author and timestamp	Completed
FR-07	Study Rooms	Create, list, and join study rooms (public or by join code), owner manages their own rooms	Completed
FR-08	Messaging	Real time messaging in study rooms via WebSocket, list, send, and delete own messages	Completed
FR-09	AI Assistant	Ask questions, summarize, and analyze research using Groq/HF models, manage own conversations and message history	Completed
FR-10	Dashboard & Analytics	Personalized dashboard showing a user's own activity, insights, and trends	Completed
FR-11	File Management	Generate signed upload/download URLs, delete own files with access checks, ensure buckets exist	Completed

Req. No.	Requirement Name	Requirement Description	Status
FR-12	Research Hub	Blockchain integrated medical research analytics hub showing disease frequency, symptom analysis, and treatment effectiveness from anonymized population health data	Completed
FR 13	Analytics	Advanced population health analytics with co occurrence patterns, treatment effectiveness metrics, and comprehensive medical data visualization from blockchain sources	Completed

3.3.1.3 Authority Platform Module Requirements

Table 3.3: Authority Platform Module - Functional Requirements

Req. No.	Requirement Name	Requirement Description	Status
FR-01	Authority Authentication	Authority person email/password authentication using Supabase, email verification required, secure session management with role based access	Completed
FR-02	Authority Profiles	Authority person profiles with personal details, contact information, and profile management, optional avatar upload to Supabase Storage	Completed
FR-03	Statistics Upload	Upload health statistics reports with essential metadata including category, title, description, and data files, multi-file support with basic validation	Completed
FR-04	Statistics Search	Search and browse statistical reports with filtering by category and basic search functionality across titles and descriptions	Completed
FR-05	Statistics Viewing	View detailed statistical reports with metadata, author information, and secure file downloads, basic view tracking for analytics	Completed

Req. No.	Requirement Name	Requirement Description	Status
FR-06	Comments System	Authority collaboration through commenting on statistical reports with data quality checks and validation feedback as extended functionality	Completed
FR-07	Analytics Dashboard	Health analytics dashboard with platform overview, personal statistics, and blockchain health data integration with real time health trends visualization	Completed
FR-08	Blockchain Integration	Real time blockchain health data analytics including disease trends, and health metrics from verified blockchain sources independent of Supabase	Completed

3.3.2 Non Functional Requirements

3.3.2.1 Healthcare Application Module Non Functional Requirements

Table 3.4: Healthcare Application Module Non Functional Requirements

Req. No.	Requirement Name	Requirement Description	Status
NFR1	Performance	System handles high user load with fast response times	Completed
NFR2	Reliability	High availability with minimal downtime	Completed
NFR3	Security	Robust data protection and access controls	Completed
NFR4	Scalability	Supports growing user base and data volume	Completed
NFR5	Maintainability	Easy to update and modify system components	Completed
NFR6	Usability	Intuitive interface accessible to all users	Completed
NFR7	Compliance	Meets healthcare data regulations and standards	Completed
NFR8	Interoperability	Works with other healthcare systems and platforms	Completed

3.3.2.2 Researcher Platform Module Non Functional Requirements

Table 3.5: Researcher Platform Module - Non Functional Requirements

Req. No.	Requirement Name	Requirement Description	Status
NFR-01	Performance	Typical page load < 10 seconds on broadband, WebSocket chat latency < 500 ms, AI response target < 5 seconds	Completed
NFR-02	Security	Supabase JWT auth, RLS policies, time bound signed URLs, server side validation (Zod), and sanitized file handling	Completed
NFR-05	Usability	Responsive UI (Tailwind + shadcn/ui), accessible forms, clear error states, and keyboard navigation	Completed
NFR-06	Compatibility	Support latest Chrome, Edge, Firefox, and Safari, mobile friendly layouts	Completed
NFR-08	Maintainability	TypeScript across client/server, modular architecture, shared Zod schemas, and lint ready build	Completed

3.3.2.3 Authority Platform Module Non Functional Requirements

Table 3.6 : Authority Platform Module Non Functional Requirements

Req. No.	Requirement Name	Requirement Description	Status
NFR-01	Performance	Dashboard load time < 10 seconds, file upload processing < 30 seconds for files up to 10MB, analytics chart rendering < 10 seconds with reasonable data sets	Completed
NFR-02	Security	Secure authentication with Supabase JWT, Row Level Security policies, encrypted file storage, and basic access controls for health data protection	Completed
NFR-05	Usability	Clean, professional interface with responsive design, intuitive navigation for authority persons, clear error messaging and user feedback	Completed

Req. No.	Requirement Name	Requirement Description	Status
NFR-06	Compatibility	Support for modern web browsers, mobile responsive design, standard web technologies without special institutional requirements	Completed
NFR-07	Data Protection	Basic privacy protection for health statistics, secure data handling, user consent and data access controls	Completed
NFR-08	Data Integrity	Basic data validation, file integrity checks, secure upload/download processes, standard backup procedures through Supabase	Completed
NFR-09	Maintainability	TypeScript codebase for type safety, modular React/Express architecture, clear documentation, basic testing coverage	Completed

3.4 System Use Case Modeling

The HARMONY ecosystem includes the detailed use case modeling that shows the pattern of interaction and the functional workflow of all the three modules integrated. In this section, it is given in a hierarchical format beginning with the unified system use case diagram for each module thereafter specifications and flow descriptions of the specific module are given.

3.4.1 Main HARMONY System Use Case

As depicted in the main system use case diagram, the entire HARMONY ecosystem consists of an interaction between the three modules (Healthcare Application, Researcher Platform, and Authority Platform): they interact to be part of a single blockchain based healthcare data management system. The given diagram shows the system wide scope and interrelatedness of all three platforms.

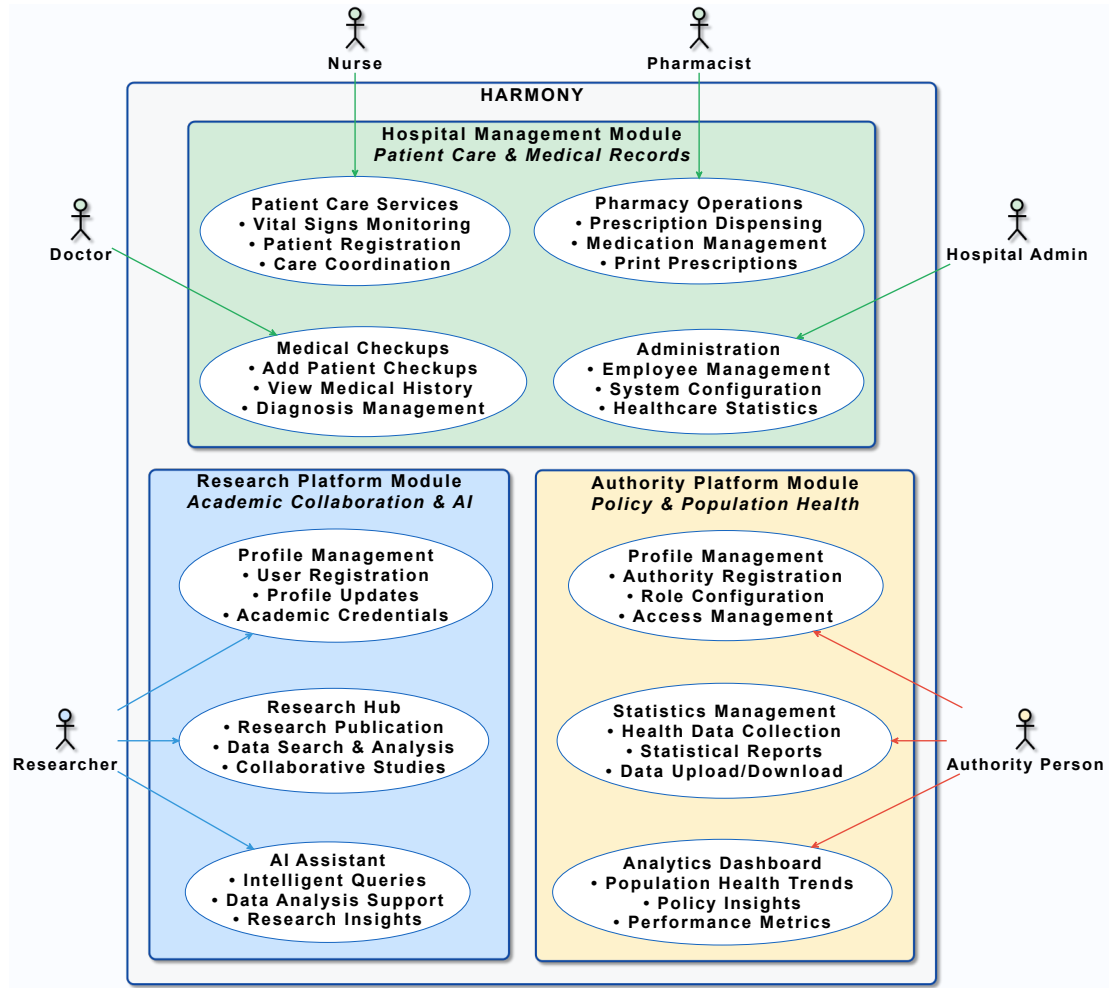


Figure 3.1: HARMONY System Use Case Diagram

The unified use case diagram illustrates the way HARMONY will be utilized by three distinct yet interrelated groups of users, namely, hospital personnel tasked with the duty to manage patients, researchers who will take part in medical research, and government officials who will monitor the health of the population. The system will offer smooth integration of data and appropriate access control and privacy measures to the various categories of users.

3.4.2 Healthcare Application Module Use Cases

The Hospital Application module provides healthcare institutions with comprehensive use cases for patient care, medical record management, and role based

healthcare operations. The system enables secure patient data management through blockchain technology and supporting multi role healthcare workflows. This module empowers healthcare professionals with patient registration, medical record access, prescription management, and comprehensive patient care coordination across different hospital departments.

3.4.2.1 Hospital System Use Case

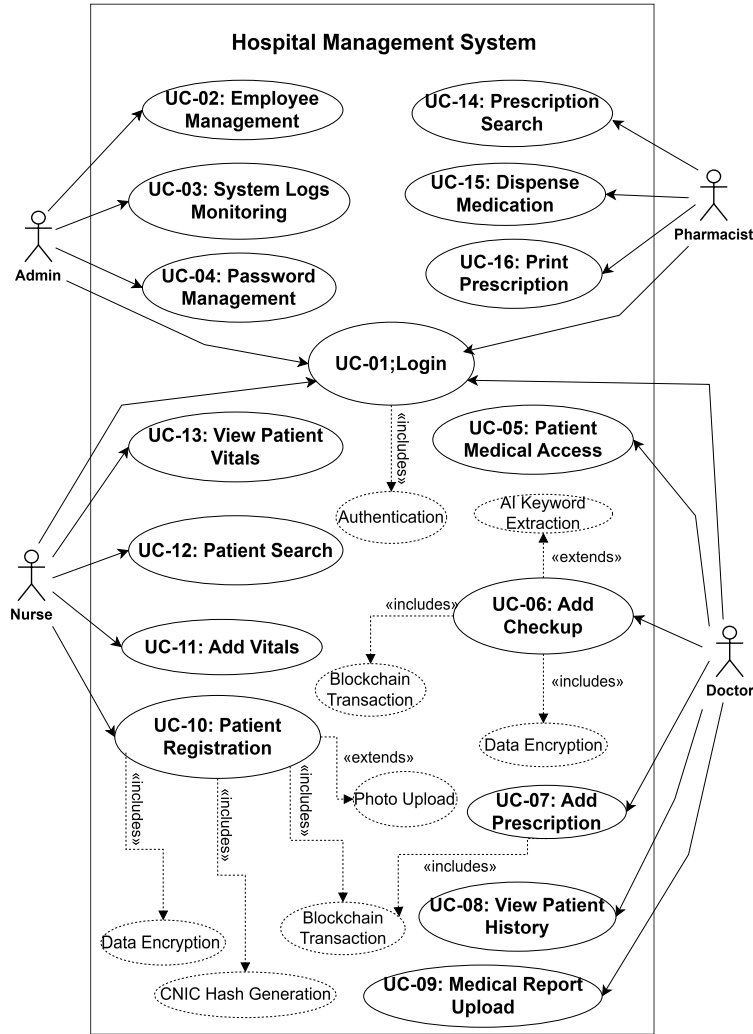


Figure 3.2 : Hospital Management System Use Case Diagram

3.4.2.2 Detailed Use Case Specifications

Use Case: UC-01 Employee Login

Table 3.7 : Use Case 01 - Employee Login

Use Case ID:	UC-01		
Use Case Name:	Employee Login		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Admin, Doctor, Nurse, Pharmacist		
Trigger:	Employee navigates to hospital authentication page.		
Description:	Hospital employees authenticate using credentials with role based access verification.		
Preconditions:	Employee account exists, hospital system operational, database accessible.		
Post conditions:	Employee session established, redirected to role specific dashboard.		
Normal Flow:	#	Actor	System
	1	Enters employee ID and password.	Validates credentials and role permissions.
	2	Submits login form.	Establishes secure session, loads employee profile.
	3		Redirects to role specific dashboard interface.
Alternative Flows:	• Password reset required → Admin manages password reset. • Account locked → contact admin.		
Exceptions:	• Invalid credentials or inactive employee account. • Authentication service unavailable. • Role permissions not properly configured.		

Use Case: UC-02 Employee Management

Table 3.8 : Use Case 02 - Employee Management

Use Case ID:	UC-02		
Use Case Name:	Employee Management		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Admin		
Trigger:	Admin navigates to employee management section.		
Description:	Admin manages hospital employee accounts including creation, modification, and role assignment.		
Preconditions:	Admin authenticated, employee database accessible, role management system operational.		
Post conditions:	Employee records updated, role permissions configured, system notifications sent.		
Normal Flow:	#	Actor	System
	1	Accesses employee list and selects action.	Displays current employee roster with role information.
	2	Creates or modifies employee details and role.	Validates employee information and role permissions.
	3	Assigns department and access permissions.	Updates employee database and configures system access.
Alternative Flows:	- Employee deactivation → disables access while preserving records. - Bulk employee import → processes multiple employee records.		
Exceptions:	- Duplicate employee ID or invalid role assignment. - Database constraint violations or permission conflicts. - Email notification failures during account creation.		

Use Case: UC-03 System Logs Monitoring

Table 3.9 : Use Case 03 - System Logs Monitoring

Use Case ID:	UC-03		
Use Case Name:	System Logs Monitoring		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Admin		
Trigger:	Admin accesses system monitoring dashboard.		
Description:	Admin monitors system activities, audit trails, and security logs for compliance and troubleshooting.		
Preconditions:	Admin authenticated, logging system operational, audit trail accessible.		
Post conditions:	System status displayed, logs filtered and exported, security alerts reviewed.		
Normal Flow:	#	Actor	System
	1	Selects log type and time range for monitoring.	Retrieves relevant log entries and system metrics.
	2	Applies filters for specific events or users.	Processes filter criteria and updates log display.
	3	Reviews security alerts and system performance.	Highlights critical events and generates status reports.
Alternative Flows:	- Real time monitoring → displays live system activity feed. - Log export → generates downloadable compliance reports.		
Exceptions:	- Log database unavailable or corrupted entries. - Performance issues with large log datasets. - Export failures due to file size limitations.		

Use Case: UC-04 Password Management

Table 3.10 : Use Case 04 - Password Management

Use Case ID:	UC-04		
Use Case Name:	Password Management		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Admin		
Trigger:	Admin initiates password change or reset request.		
Description:	Admin manage all password changes and security with frequent changes and following strong password con.		
Preconditions:	Admin logged in, Authorized, Employee exists.		
Post conditions:	Password updated securely, login credentials refreshed.		
Normal Flow:	#	Actor	System
	1	Enters current password and new password.	Validates current credentials and new password policy.
	2	Confirms new password entry.	Verifies password strength and policy compliance.
	3	Submits password change request.	Updates password hash and invalidates old sessions.
Alternative Flows:	N/A		
Exceptions:	N/A		

Use Case: UC-05 Patient Medical Access

Table 3.11 : Use Case 05 - Patient Medical Access

Use Case ID:	UC-05		
Use Case Name:	Patient Medical Access		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Doctor, Nurse		
Trigger:	Healthcare provider accesses patient medical records.		
Description:	Healthcare providers access comprehensive patient medical information with role-based permissions.		
Preconditions:	Provider authenticated, patient exists in system, blockchain records accessible.		
Post conditions:	Medical records displayed, access logged for audit, patient privacy maintained.		
Normal Flow:	#	Actor	System
	1	Searches for patient using CNIC or name.	Validates provider permissions and patient access rights.
	2	Selects patient from search results.	Retrieves medical records from blockchain and database.
	3	Reviews comprehensive medical history.	Displays records with audit logging and privacy controls.
Alternative Flows:	N/A		
Exceptions:	• Patient records not found or access denied. • Blockchain connectivity issues affecting record retrieval. • Privacy restrictions preventing full record access.		

Use Case: UC-06 Add Checkup

Table 3.12 : Use Case 06 - Add Checkup

Use Case ID:	UC-06		
Use Case Name:	Add Checkup		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Doctor		
Trigger:	Doctor completes patient examination and needs to record findings.		
Description:	Doctor records comprehensive checkup information including symptoms, diagnosis, and treatment plans.		
Preconditions:	Doctor authenticated, patient selected, examination completed, blockchain accessible.		
Post conditions:	Checkup recorded in blockchain, medical history updated, treatment plan documented.		
Normal Flow:	#	Actor	System
	1	Enters patient symptoms and chief complaint.	Validates patient information and checkup form data.
	2	Records examination findings and diagnosis.	Processes medical terminology and diagnostic codes.
	3	Documents treatment plan and recommendations.	Stores checkup data in blockchain and updates history.
Alternative Flows:	Follow-up scheduling → automatically schedules next appointment.		
Exceptions:	- Blockchain transaction failures during record storage. - Invalid medical codes or incomplete examination data. - System timeout during checkup data submission.		

Use Case: UC-07 Add Prescription

Table 3.13 : Use Case 07 - Add Prescription

Use Case ID:	UC-07		
Use Case Name:	Add Prescription		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Doctor		
Trigger:	Doctor prescribes medications following patient examination.		
Description:	Doctor creates digital prescriptions with medication details, dosage, and safety checks.		
Preconditions:	Doctor authenticated, patient checkup completed, medication database accessible.		
Post conditions:	Prescription stored in blockchain, pharmacy notified, patient medication history updated.		
Normal Flow:	#	Actor	System
	1	Selects medications and specifies dosage instructions.	Validates medication availability and drug interactions.
	2	Reviews prescription details and patient allergies.	Checks contraindications and provides safety warnings.
	3	Confirms and submits digital prescription.	Stores prescription in blockchain and notifies pharmacy.
Alternative Flows:	• Drug interaction alert → requires doctor confirmation to proceed. • Generic substitution → suggests cost-effective alternatives.		
Exceptions:	• Medication not found in formulary or discontinued. • Dosage calculation errors or invalid instructions. • Blockchain storage failures affecting prescription validity.		

Use Case: UC-08 View Patient History

Table 3.14 : Use Case 08 - View Patient History

Use Case ID:	UC-08		
Use Case Name:	View Patient History		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Doctor, Nurse		
Trigger:	Healthcare provider needs to review patient's medical history.		
Description:	Healthcare providers access chronological patient medical history with filtering and search capabilities.		
Preconditions:	Provider authenticated, patient selected, medical records accessible via blockchain.		
Post conditions:	Medical history displayed chronologically, relevant records highlighted, access logged.		
Normal Flow:	#	Actor	System
	1	Accesses patient history from patient profile.	Retrieves comprehensive medical records from blockchain.
	2	Applies filters for date range or record type.	Processes filter criteria and updates history display.
	3	Reviews detailed medical events and treatments.	Displays timeline view with expandable record details.
Alternative Flows:	• Summary view → displays condensed medical history overview. • Print history → generates printable medical history report.		
Exceptions:	• Incomplete medical records or blockchain sync issues. • Performance problems with extensive medical histories. • Access restrictions for sensitive historical records.		

Use Case: UC-09 Medical Report Upload

Table 3.15 : Use Case 09 - Medical Report Upload

Use Case ID:	UC-09		
Use Case Name:	Medical Report Upload		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Doctor, Nurse		
Trigger:	Healthcare provider uploads medical reports, lab results, or imaging studies.		
Description:	Healthcare providers securely upload and attach medical documents to patient records.		
Preconditions:	Provider authenticated, patient selected, file storage and blockchain accessible.		
Post conditions:	Medical reports uploaded securely, linked to patient records, accessible for future reference.		
Normal Flow:	#	Actor	System
	1	Selects medical files and specifies report type.	Validates file format, size, and medical content type.
	2	Adds report metadata and clinical context.	Processes metadata and prepares for secure storage.
	3	Confirms upload and links to patient record.	Encrypts files, stores in cloud, updates blockchain record.
Alternative Flows:	• Bulk upload → processes multiple reports simultaneously. • Report annotation → allows providers to add clinical notes.		
Exceptions:	• File size exceeds limits or unsupported format. • Cloud storage failures or encryption errors. • Blockchain transaction failures during record linking.		

Use Case: UC-10 Patient Registration

Table 3.16 : Use Case 10 - Patient Registration

Use Case ID:	UC-10		
Use Case Name:	Patient Registration		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Nurse		
Trigger:	New patient arrives for registration or existing patient updates information.		
Description:	Nurse registers new patients or updates existing patient information in the hospital system.		
Preconditions:	Nurse authenticated, registration system operational, blockchain network accessible.		
Post conditions:	Patient registered successfully, medical record created, unique patient ID assigned.		
Normal Flow:	#	Actor	System
	1	Collects patient demographic and contact information.	Validates CNIC format and checks for existing records.
	2	Records emergency contact and insurance details.	Processes insurance verification and contact validation.
	3	Submits complete registration information.	Creates patient record in blockchain and assigns unique ID.
Alternative Flows:	- Existing patient update → modifies current patient information. - Emergency registration → allows minimal information for urgent cases.		
Exceptions:	- Duplicate CNIC detected or invalid identification documents. - network connectivity issues. - Blockchain transaction failures during patient record creation.		

Use Case: UC-11 Add Vitals

Table 3.17 : Use Case 11 - Add Vitals

Use Case ID:	UC-11		
Use Case Name:	Add Vitals		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Nurse		
Trigger:	Nurse measures and records patient vital signs during routine care.		
Description:	Nurse records comprehensive vital signs including blood pressure, heart rate, temperature, and oxygen saturation.		
Preconditions:	Nurse authenticated, patient selected, vital signs measured, recording system operational.		
Post conditions:	Vital signs recorded in blockchain, trends updated, alerts generated for abnormal values.		
Normal Flow:	#	Actor	System
	1	Enters vital signs measurements and timestamp.	Validates vital sign ranges and measurement accuracy.
	2	Reviews entered values for accuracy.	Compares with normal ranges and previous readings.
	3	Submits vital signs record.	Stores in blockchain, updates trends, generates alerts if needed.
Alternative Flows:	• Critical values → immediately alerts healthcare team. • Trend analysis → displays historical vital signs patterns.		
Exceptions:	• Values outside acceptable ranges or measurement errors. • Equipment malfunction affecting vital signs accuracy. • Blockchain storage failures during vital signs recording.		

Use Case: UC-12 Patient Search

Table 3.18 : Use Case 12 - Patient Search

Use Case ID:	UC-12		
Use Case Name:	Patient Search		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Doctor, Nurse, Pharmacist		
Trigger:	Healthcare provider searches for patient records using various criteria.		
Description:	Healthcare providers search for patients using CNIC, name, phone number, or patient ID.		
Preconditions:	Provider authenticated, patient database accessible, search functionality operational.		
Post conditions:	Patient search results displayed, relevant patient selected, access permissions verified.		
Normal Flow:	#	Actor	System
	1	Enters search criteria (CNIC, name, or phone).	Validates search parameters and applies privacy filters.
	2	Reviews search results and patient matches.	Displays matching patients with basic information.
	3	Selects correct patient from results.	Verifies access permissions and loads patient profile.
Alternative Flows:	- Advanced search → uses multiple criteria for refined results. - No results found → suggests patient registration process.		
Exceptions:	- Invalid search criteria or malformed patient identifiers. - Too many results requiring additional filter criteria. - Database connectivity issues affecting search performance.		

Use Case: UC-13 View Patient Vitals

Table 3.19 : Use Case 13 - View Patient Vitals

Use Case ID:	UC-13		
Use Case Name:	View Patient Vitals		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Doctor, Nurse		
Trigger:	Healthcare provider accesses patient vital signs for clinical assessment.		
Description:	Healthcare providers view comprehensive vital signs history with trends and analysis.		
Preconditions:	Provider authenticated, patient selected, vital signs data accessible via blockchain.		
Post conditions:	Vital signs displayed with trends, critical values highlighted, clinical context provided.		
Normal Flow:	#	Actor	System
	1	Accesses vital signs from patient dashboard.	Retrieves comprehensive vital signs history from blockchain.
	2	Selects time range and vital sign type filters.	Processes filter criteria and updates vital signs display.
	3	Reviews trends and identifies abnormal patterns.	Highlights critical values and provides trend analysis.
Alternative Flows:	- Real-time monitoring → displays current vital signs if connected. - Comparative analysis → compares with previous admission periods.		
Exceptions:	- Missing vital signs data or incomplete measurements. - Chart rendering issues with extensive historical data. - Blockchain connectivity problems affecting data retrieval.		

Use Case: UC-14 Prescription Search

Table 3.20 : Use Case 14 - Prescription Search

Use Case ID:	UC-14		
Use Case Name:	Prescription Search		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Pharmacist		
Trigger:	Pharmacist searches for patient prescriptions for medication dispensing.		
Description:	Pharmacist searches and retrieves valid prescriptions using patient identifiers or prescription numbers.		
Preconditions:	Pharmacist authenticated, prescription database accessible, blockchain network operational.		
Post conditions:	Prescription results displayed, validity verified, ready for medication dispensing process.		
Normal Flow:	#	Actor	System
	1	Enters patient CNIC or prescription number.	Validates search criteria and queries prescription database.
	2	Reviews available prescriptions and status.	Displays prescriptions with validity and dispensing status.
	3	Selects prescription for medication dispensing.	Verifies prescription authenticity and prepares dispensing workflow.
Alternative Flows:	- Multiple prescriptions → displays all active prescriptions for patient. - Expired prescriptions → shows expired prescriptions with renewal options.		
Exceptions:	- Invalid prescription number or patient not found. - Prescription already dispensed or expired validity. - Blockchain verification failures affecting prescription authenticity.		

Use Case: UC-15 Dispense Medication

Table 3.21 : Use Case 15 - Dispense Medication

Use Case ID:	UC-15		
Use Case Name:	Dispense Medication		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Pharmacist		
Trigger:	Pharmacist processes medication dispensing after prescription verification.		
Description:	Pharmacist dispenses medications according to valid prescriptions with safety checks and inventory management.		
Preconditions:	Valid prescription selected, medication available in inventory, dispensing system operational.		
Post conditions:	Medication dispensed, prescription marked as fulfilled, inventory updated, patient counseled.		
Normal Flow:	#	Actor	System
	1	Verifies prescription details and patient identity.	Validates prescription authenticity and patient information.
	2	Checks medication availability and substitutions.	Verifies inventory levels and suggests alternatives if needed.
	3	Dispenses medication and provides patient counseling.	Updates inventory, marks prescription fulfilled, records dispensing.
Alternative Flows:	N/A		
Exceptions:	N/A		

Use Case: UC-16 Print Prescription

Table 3.22 : Use Case 16 - Print Prescription

Use Case ID:	UC-16		
Use Case Name:	Print Prescription		
Created By:	Muhammad Daud		
Last Updated By:	Muhammad Daud		
Actors:	Pharmacist		
Trigger:	Pharmacist needs to print prescription labels or patient medication instructions.		
Description:	Pharmacist generates and prints prescription labels, medication instructions, and dispensing documentation.		
Preconditions:	Prescription processed, medication dispensed, printer system operational and configured.		
Post conditions:	Prescription labels printed, medication instructions provided, dispensing documentation completed.		
Normal Flow:	#	Actor	System
	1	Selects prescription for label printing.	Formats prescription data for label template generation.
	2	Reviews label information and patient instructions.	Validates label accuracy and medication safety information.
	3	Prints prescription labels and instruction sheets.	Sends formatted documents to printer and confirms printing.
Alternative Flows:	• Patient instruction sheets → generates detailed medication guides.		
Exceptions:	• Template formatting errors or incomplete prescription data. • Network connectivity issues preventing print job submission.		

3.4.3 Researcher Platform Module Use Cases

The Researcher Platform module encompasses a comprehensive set of use cases that enable medical researchers and students to collaborate, analyze data, and share research findings securely. The system integrates advanced features including AI-powered analysis, blockchain secured medical data analytics, real time collaboration, and secure file management.

3.4.3.1 Researcher System Use Case

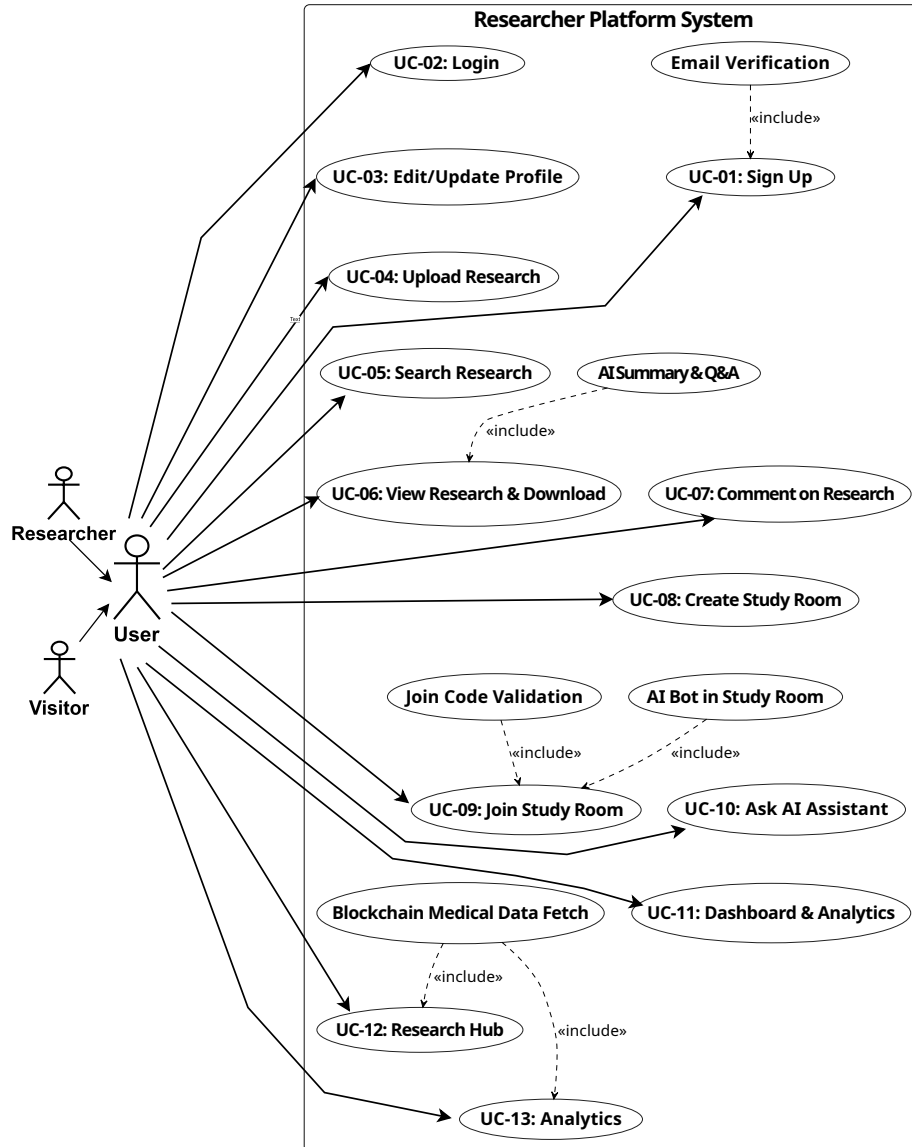


Figure 3.3: Researcher Platform System Use Case Diagram

3.4.3.2 Detailed Use Case Specifications

Use Case: UC-17 Sign Up

Table 3.23 : Use Case 17 - Sign Up

Use Case ID:	UC-17		
Use Case Name:	Sign Up		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	Visitor		
Trigger:	Visitor creates new account from Auth page.		
Description:	User registers with email verification and basic profile setup.		
Preconditions:	Email not registered, network connectivity available.		
Post conditions:	Verified account exists, user redirected to dashboard.		
Normal Flow:	#	Actor	System
	1	Enters name, email, password, optional avatar.	Validates input, creates account and sends verification email.
	2	Opens email link to confirm.	Verifies token, activates account.
	3	Provides profile details (gender, age, institution).	Saves profile, redirects to dashboard.
Alternative Flows:	- Email exists → show message and suggest Login. - Skip profile → minimal profile kept, update later.		
Exceptions:	- Invalid email/password format. - Verification link expired. - Network error during creation.		

Use Case: UC-18 Login

Table 3.24: Use Case 18 - Login

Use Case ID:	UC-18		
Use Case Name:	Login		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User		
Trigger:	User logs in with existing credentials.		
Description:	User authenticates via email/password using Supabase Auth. System validates credentials and redirects to dashboard.		
Preconditions:	User account exists and email verified.		
Post conditions:	User session established, redirected to dashboard.		
Normal Flow:	#	Actor	System
	1	Navigates to /auth page.	Displays login form.
	2	Enters email and password.	Validates input format.
	3	Submits login form.	Calls Supabase Auth, validates credentials.
	4		Establishes session and generates JWT token.
	5		Fetches user profile and redirects to dashboard.
Alternative Flows:	- Email not verified → error with resend option. - Invalid credentials → error with retry. - Token expired → auto-refresh or redirect to login.		
Exceptions:	- Invalid email format or empty password. - Auth service unavailable. - Account disabled. - Session validation fails.		

Use Case: UC-19 Edit/Update Profile

Table 3.25: Use Case 19 - Edit/Update Profile

Use Case ID:	UC-19		
Use Case Name:	Edit/Update Profile		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User		
Trigger:	User navigates to profile editing page.		
Description:	User updates profile information including personal details, avatar, email, and password.		
Preconditions:	User authenticated with access to profile-edit page.		
Post conditions:	Profile updated in database, changes reflected in UI.		
Normal Flow:	#	Actor	System
	1	Navigates to /profile/edit page.	Loads current profile data and displays edit form.
	2	Modifies profile fields (name, bio, institution, age).	Validates input in real time.
	3	Optionally uploads new avatar image.	Validates file type/size, creates preview.
	4	Optionally updates email or password.	Validates email uniqueness and password strength.
	5	Submits profile update form.	Processes changes, uploads avatar, updates database.
	6		Returns success confirmation.
Alternative Flows:	• Password only → update password without other changes. • Avatar removal → remove existing avatar. • Partial update → update selected fields only.		
Exceptions:	• Invalid file type/size for avatar. • Current password verification fails. • Email already exists. • Network error or service unavailable.		

Use Case: UC-20 Upload Research

Table 3.26: Use Case 20 - Upload Research

Use Case ID:	UC-20		
Use Case Name:	Upload Research		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User		
Trigger:	User selects "Upload Research" from dashboard.		
Description:	User uploads research files with metadata, server processes and stores records.		
Preconditions:	User authenticated, storage bucket available.		
Post conditions:	Research record created, files accessible via signed URLs.		
Normal Flow:	#	Actor	System
	1	Provides title, abstract, tags, and selects files.	Validates input, requests signed upload URL.
	2	Confirms submission.	Uploads files, creates DB record, returns success.
Alternative Flows:	• Upload fails → allow retry, keep draft.		
Exceptions:	• File exceeds size/unsupported type. • Storage or network failure.		

Use Case: UC-21 Search Research

Table 3.27: Use Case 21 - Search Research

Use Case ID:	UC-21		
Use Case Name:	Search Research		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User, Visitor		
Trigger:	User navigates to research search page.		
Description:	Users search and filter public research using keywords, tags, author, and institution criteria.		
Preconditions:	Research database available, search API endpoint accessible.		
Post conditions:	Filtered results displayed, search parameters saved in URL.		
Normal Flow:	#	Actor	System
	1	Navigates to search page.	Displays search interface with filter options.
	2	Enters search query and selects filters.	Validates input, updates form state.
	3	Submits search.	Queries database, returns matching results as cards.
Alternative Flows:	• No results → display message with reset option. • Reset filters → clear filters, show all research.		
Exceptions:	• Search API unavailable. • Invalid search parameters. • Network timeout.		

Use Case: UC-22 View Research and Download

Table 3.28: Use Case 22 - View Research and Download

Use Case ID:	UC-22		
Use Case Name:	View Research and Download		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User, Visitor		
Trigger:	User clicks on research card to view details.		
Description:	Users view comprehensive research details, metadata, and download files using signed URLs.		
Preconditions:	Research exists, user has viewing permissions.		
Post conditions:	Research displayed, view count incremented, download URLs generated.		
Normal Flow:	#	Actor	System
	1	Navigates to research detail page.	Fetches research details, validates permissions.
	2		Displays content, comments, and file download options.
	3	Clicks download button.	Generates signed URL, opens file in new tab.
	4	Clicks "Explore with AI".	Creates AI conversation, redirects to assistant.
Alternative Flows:	• Research not found → display error message. • No file attached → hide download section. • Unauthorized access → show permission denied.		
Exceptions:	• Invalid research ID. • File download fails. • Database connection error. • AI service unavailable.		

Use Case: UC-23 Comment on Research

Table 3.29: Use Case 23 - Comment on Research

Use Case ID:	UC-23		
Use Case Name:	Comment on Research		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User		
Trigger:	Authenticated user navigates to public research and wants to comment.		
Description:	Users post comments on public research for academic discussion, authors receive notifications.		
Preconditions:	User authenticated, research is public and accessible.		
Post conditions:	Comment stored, appears in research list, author notified, statistics updated.		
Normal Flow:	#	Actor	System
	1	Navigates to research detail page.	Displays research content and existing comments.
	2	Types comment and clicks "Post Comment".	Validates input, creates comment record with author info.
	3		Returns comment data, refreshes list, notifies author.
	4		System validates user authentication and research visibility permissions.
	5		System creates comment record, returns data, refreshes list, notifies author.
Alternative Flows:	• Private research → hide comment form. • Empty comment → disable submit until valid text.		
Exceptions:	• Comment validation fails. • Session expires during posting. • Network error or API unavailable. • Database constraint violation.		

Use Case: UC-24 Create Study Room

Table 3.30: Use Case 24 - Create Study Room

Use Case ID:	UC-24		
Use Case Name:	Create Study Room		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User		
Trigger:	Authenticated user clicks "Create Room" to establish new study environment.		
Description:	Users create public or private study rooms for collaboration, private rooms generate secure join codes.		
Preconditions:	User authenticated, room name unique in system.		
Post conditions:	Study room created, creator added as member, join code generated for private rooms.		
Normal Flow:	#	Actor	System
	1	Clicks "Create Room" button.	Opens creation dialog with form fields.
	2	Enters room name and selects visibility (Public/Private).	Validates name, shows/hides passcode field.
	3	Optionally sets passcode for private rooms.	Validates passcode requirements.
	4	Submits creation form.	Validates data, creates room, generates join code, adds creator as member.
	5		Displays success with room details, refreshes room lists.
Alternative Flows:	- Public room → skip passcode, create without join code. - Form validation errors → display field errors, prevent submission.		
Exceptions:	- Room name already exists. - Invalid form data validation. - Authentication expires during creation. - Database or network issues.		

Use Case: UC-25 Join Study Room

Table 3.31: Use Case 25 - Join Study Room

Use Case ID:	UC-25		
Use Case Name:	Join Study Room		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User		
Trigger:	Authenticated user wants to join existing study room via discovery or join code.		
Description:	Users join public rooms directly or private rooms using passcode authentication, system validates membership.		
Preconditions:	User authenticated, target room exists, valid passcode for private rooms.		
Post conditions:	User becomes member, room appears in "My Rooms", access to chat interface.		
Normal Flow:	#	Actor	System
	1	Browses available rooms and clicks "Join Room".	Displays rooms, identifies room type, initiates join process.
	2	For private rooms: enters passcode in dialog.	Validates passcode, checks membership, creates record.
	3		Returns confirmation, refreshes lists, enters chat with WebSocket.
Alternative Flows:	• Direct join code entry → use "Join with Code" dialog. • Public room → immediate entry without passcode.		
Exceptions:	• Invalid passcode. • Room not found. • Authentication failure. • Network/database errors.		

Use Case: UC-26 Study Room Messaging

Table 3.32: Use Case 26 - Study Room Messaging

Use Case ID:	UC-26		
Use Case Name:	Study Room Messaging		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User		
Trigger:	User enters a study room.		
Description:	Users send/receive messages in real-time via WebSocket, messages persist to DB.		
Preconditions:	User is member of the room.		
Post conditions:	Message history updated, notifications delivered to online members.		
Normal Flow:	#	Actor	System
	1	Opens room and types a message.	Authenticates socket, broadcasts to room, persists message.
			Updates message state and notifies clients.
Alternative Flows:	Reconnection → system resyncs recent messages upon reconnect.		
Exceptions:	Network interruption.		

Use Case: UC-27 Ask AI Assistant

Table 3.33: Use Case 27 - Ask AI Assistant

Use Case ID:	UC-27		
Use Case Name:	Ask AI Assistant		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User		
Trigger:	User opens AI Assistant and submits a question or a research file for analysis.		
Description:	System forwards the request to Groq/HuggingFace models, responses are cached and stored in conversation history.		
Preconditions:	User is authenticated, rate limits in place.		
Post conditions:	AI response is displayed and appended to the conversation.		
Normal Flow:	#	Actor	System
	1	Enters prompt or uploads research.	Validates input, extracts text if file provided, calls AI service.
	2	Reads the response and follows suggestions.	Saves message to conversation, updates UI and analytics counters.
Alternative Flows:	Large file → summarize first, then allow follow-up questions.		
Exceptions:	- Provider timeout or quota exceeded. - Unsupported file format.		

Use Case: UC-28 Dashboard

Table 3.34: Use Case 28 - Dashboard

Use Case ID:	UC-28		
Use Case Name:	Dashboard		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User		
Trigger:	Authenticated user navigates to main dashboard or logs into system.		
Description:	System provides personalized dashboard with user statistics, recent activities, and quick platform access.		
Preconditions:	User authenticated, profile exists, dashboard endpoints available.		
Post conditions:	Dashboard displays statistics and activities, navigation enabled, data cached.		
Normal Flow:	#	Actor	System
	1	Navigates to dashboard URL.	Validates authentication, loads dashboard interface.
	2		Displays welcome message, checks admin status for redirect.
	3		Fetches and displays statistics, recent research, and comments.
	4		Provides quick navigation links to platform features.
Alternative Flows:	- No user data → display welcome message for new users. - API unavailable → show skeleton with fallback data.		
Exceptions:	- Session expired → redirect to login. - API failures → show error messages. - Network issues → show cached data or retry.		

Use Case: UC-29 Research Hub

Table 3.35: Use Case 29 - Research Hub

Use Case ID:	UC-29		
Use Case Name:	Research Hub		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User		
Trigger:	User navigates to Research Hub to analyze population health data.		
Description:	System provides medical research analytics using blockchain-secured anonymized medical data with disease patterns and correlations.		
Preconditions:	User authenticated, blockchain medical data available, analytics system operational.		
Post conditions:	Medical analytics displayed with interactive visualizations, search results with privacy protection.		
Normal Flow:	#	Actor	System
	1	Navigates to Research Hub page.	Displays hub interface, fetches blockchain medical data.
	2		Processes data, displays analysis categories and statistics.
	3	Selects analysis category (Disease/Symptom/Treatment).	Shows interactive charts with medical analytics.
	4	Uses medical records search.	Provides search interface, displays anonymized records.
Alternative Flows:	- Advanced pattern analysis → provide co-occurrence relationships. - Export analytics → download analysis results and charts.		
Exceptions:	- Blockchain data unavailable → show cached data. - Privacy validation errors → ensure anonymization.		

Use Case: UC-30 Analytics

Table 3.36: Use Case 30 - Analytics

Use Case ID:	UC-30		
Use Case Name:	Analytics		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	User		
Trigger:	User navigates to Analytics page for advanced population health analytics.		
Description:	System provides advanced medical analytics dashboard with co-occurrence patterns, and treatment effectiveness tracking.		
Preconditions:	User authenticated, blockchain medical data accessible, analytics engines operational.		
Post conditions:	Analytics dashboard displays interactive visualizations, filtered results computed, reports exportable.		
Normal Flow:	#	Actor	System
	1	Navigates to Analytics page.	Displays dashboard with blockchain connection status.
	2		Fetches medical data, displays view tabs and filter controls.
	3	Selects view (Co occurrence/Treatment).	Shows corresponding charts and analysis.
	4	Applies filters (time, disease, location).	Re processes data, updates visualizations dynamically.
	5	Clicks "Export Report".	Generates comprehensive analytics report.
Alternative Flows:	• No filtered results → suggest filter modifications. • Real time updates → auto refresh with new data. • Interactive exploration → drill down into specific patterns.		
Exceptions:	• Blockchain connectivity issues → use cached data. • Analytics processing errors → offer retry options.		

3.4.4 Authority Platform Module Use Cases

The Authority Platform module provides government health agencies with comprehensive use cases for health surveillance, statistical report management, and blockchain powered population health analytics. The system enables secure data sharing between government agencies and healthcare institutions while

maintaining privacy and regulatory compliance. This module empowers health authorities with real time disease surveillance, statistical report management, and blockchain powered analytics for trend detection and policy decision support.

3.4.4.1 Authority System Use Case

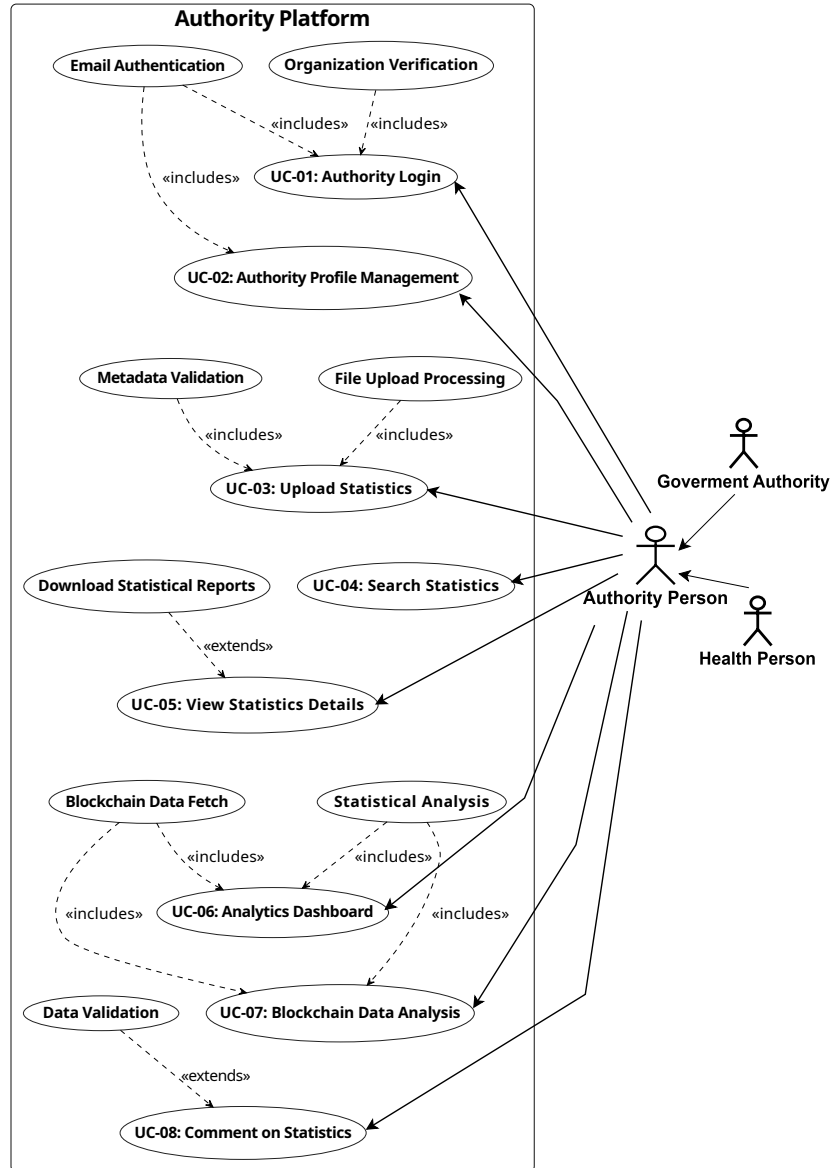


Figure 3.4: Authority Platform System Use Case Diagram

3.4.4.2 Detailed Use Case Specifications

Use Case: UC-31 Authority Login

Table 3.37 : Use Case 31 - Authority Login

Use Case ID:	UC-31		
Use Case Name:	Authority Login		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	Authority Person		
Trigger:	Authority navigates to authentication page.		
Description:	Government authority authenticates using email/password with organization verification.		
Preconditions:	Verified authority account exists, organization approved.		
Post conditions:	Authority session established, redirected to analytics dashboard.		
Normal Flow:	#	Actor	System
	1	Enters government email and password.	Validates credentials and organization status.
	2	Submits login form.	Establishes secure session, fetches authority profile.
	3		Redirects to analytics dashboard.
Alternative Flows:	Email not verified → show verification resend option.		
Exceptions:	- Invalid credentials or weak password format. - Authentication service unavailable.		

Use Case: UC-32 Authority Profile Management

Table 3.38: Use Case 32 - Authority Profile Management

Use Case ID:	UC-32		
Use Case Name:	Authority Profile Management		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	Authority Person		
Trigger:	Authority navigates to profile management page.		
Description:	Authority updates organization details, contact information, jurisdiction, and avatar.		
Preconditions:	Authority authenticated, access to profile edit page.		
Post conditions:	Profile updated, changes reflected in UI, verification status preserved.		
Normal Flow:	#	Actor	System
	1	Updates organization details and contact information.	Validates organization information and email domain.
	2	Optionally uploads new avatar.	Validates file type/size, creates preview.
	3	Submits profile update form.	Updates profile data, maintains verification status.
Alternative Flows:	Avatar removal → option to remove existing avatar.		
Exceptions:	- Invalid file type or size exceeding 5MB limit. - Government email domain validation fails.		

Use Case: UC-33 Upload Statistics

Table 3.39: Use Case 33 - Upload Statistics

Use Case ID:	UC-33		
Use Case Name:	Upload Statistics		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	Authority Person		
Trigger:	Authority navigates to upload page.		
Description:	Authority uploads statistical reports with metadata including category, region, and methodology.		
Preconditions:	Authority authenticated, upload permissions available, storage accessible.		
Post conditions:	Report stored, files uploaded, available for search based on visibility.		
Normal Flow:	#	Actor	System
	1	Enters title, description, and key findings.	Validates required fields and character limits.
	2	Selects category, region, time period, and tags.	Validates data consistency and suggests tags.
	3	Uploads statistical files and sets visibility.	Validates file types/size, processes upload securely.
	4	Reviews and submits complete report.	Creates database record, generates success confirmation.
Alternative Flows:	Bulk upload → processes multiple files with progress indicators.		
Exceptions:	- File size exceeds 50MB limit or unsupported type. - Storage quota exceeded or service unavailable. - Metadata validation fails for required fields.		

Use Case: UC-34 Search Statistics

Table 3.40: Use Case 34 - Search Statistics

Use Case ID:	UC-34		
Use Case Name:	Search Statistics		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	Authority Person		
Trigger:	User navigates to search page.		
Description:	Users search public statistical reports with filtering by category, region, time period, and author.		
Preconditions:	Statistics database available, search API accessible.		
Post conditions:	Filtered results displayed, search parameters preserved, navigation to detailed views.		
Normal Flow:	#	Actor	System
	1	Enters search query and selects filters.	Validates input, provides search suggestions.
	2	Selects category, region, time period, and sorting options.	Updates filter criteria, validates data consistency.
	3	Submits search or applies filters.	Queries database, applies full-text search and filters.
	4		Returns formatted results with pagination and metadata.
Alternative Flows:	- No results found → displays suggestions to modify criteria. - Advanced search → provides additional filter options.		
Exceptions:	- Search API timeout or database connection error. - Invalid search parameters or malformed filters. - Performance issues requiring pagination refinement.		

Use Case: UC-35 View Statistics Details

Table 3.41: Use Case 35 - View Statistics Details

Use Case ID:	UC-35		
Use Case Name:	View Statistics Details		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	Authority Person		
Trigger:	User clicks on statistical report from search results.		
Description:	Users view detailed report information including metadata, author details, and file downloads.		
Preconditions:	Report exists, user has permission based on visibility settings.		
Post conditions:	Report details displayed, view count incremented, secure file URLs generated.		
Normal Flow:	#	Actor	System
	1	Navigates to report detail page.	Fetches report details, validates permissions, increments view count.
	2		Displays report metadata, author info, and key findings.
	3	Clicks download button for files.	Validates permissions, generates secure download URLs.
	4		Increments download count, loads comments section.
Alternative Flows:	Private report → restricts access to authorized personnel.		
Exceptions:	- Invalid report ID or report not found. - File download fails due to storage issues. - Insufficient permissions for private report access.		

Use Case: UC-36 Analytics Dashboard

Table 3.42: Use Case 36 - Analytics Dashboard

Use Case ID:	UC-36		
Use Case Name:	Analytics Dashboard		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	Authority Person		
Trigger:	Authority navigates to analytics dashboard.		
Description:	Health analytics dashboard displaying platform metrics, blockchain health data trends, and interactive visualizations.		
Preconditions:	Authority authenticated, analytics API operational, blockchain data accessible.		
Post conditions:	Dashboard displays analytics, charts rendered, real time data synchronized.		
Normal Flow:	#	Actor	System
	1	Navigates to analytics dashboard.	Validates authentication, fetches platform statistics.
	2		Displays authority metrics, report metrics, and personal analytics.
	3		Fetches blockchain health data, renders interactive charts.
	4	Selects time and region filters.	Reprocesses data, updates visualizations accordingly.
	5	Authority applies filters for region, time period, disease type.	System updates visualizations with filtered blockchain data.
Alternative Flows:	- Real time updates → data and visualizations. - Custom configuration → allows customization of chart layouts.		
Exceptions:	- Blockchain data unavailable → displays cached data. - Chart rendering failures → provides alternative table views. - Analytics API timeout → shows retry options.		

Use Case: UC-37 Comment on Statistics

Table 3.43: Use Case 37 - Comment on Statistics

Use Case ID:	UC-37		
Use Case Name:	Comment on Statistics		
Created By:	Daud		
Last Updated By:	Daud		
Actors:	Authority Person		
Trigger:	Authority adds comments to statistical reports.		
Description:	Authority participates in collaborative discussions on statistical reports through commenting system.		
Preconditions:	Authority authenticated, report accessible, commenting permissions validated.		
Post conditions:	Comment added, participants notified, comment count updated.		
Normal Flow:	#	Actor	System
	1	Authority navigates to comments section of statistical report.	System loads existing comments and displays comment interface.
	2	Authority writes comment text with professional insights.	System validates comment content and length requirements.
	3	Authority submits comment for publication.	System stores comment in authority_stats_comments table.
	4		System displays updated comments section with new entry.
Alternative Flows:	Data Validation → Authority can provide validation feedback on statistical methodologies.		
Exceptions:	Network error during comment submission.		

Chapter 4

System Design

4.1 Unified HARMONY System Architecture

The HARMONY ecosystem employs a comprehensive, integrated architecture that seamlessly connects three critical healthcare domains: hospital operations, medical research collaboration, and government health surveillance. This unified approach ensures secure, scalable, and real time healthcare data management across all stakeholders while maintaining strict privacy protection and regulatory compliance.

The architecture is built using a modular, microservices approach that separates concerns across multiple layers while enabling seamless data integration. Each module maintains its specialized functionality while contributing to the larger healthcare ecosystem through blockchain secured data sharing and standardized API interfaces.

4.1.1 Core Architectural Principles

The HARMONY system architecture is founded on several key principles:

- **Modular Integration:** Each module (Healthcare Application, Researcher Platform, Authority Platform) operates independently while sharing data through blockchain and secure APIs.
- **Blockchain Foundation:** Hyperledger Fabric provides immutable medical record storage, audit trails, and secure data sharing across all modules.
- **Role Based Security:** Comprehensive access controls ensure that users can only access data appropriate to their role and institutional affiliation.
- **Privacy by Design:** Patient data is anonymized for research and government surveillance while maintaining full clinical detail for healthcare providers.

- **Scalable Infrastructure:** Cloud based deployment supports growing user bases and expanding data volumes across all three modules.
- **Real Time Capabilities:** Live data synchronization enables immediate updates across clinical care, research analytics, and population health monitoring.

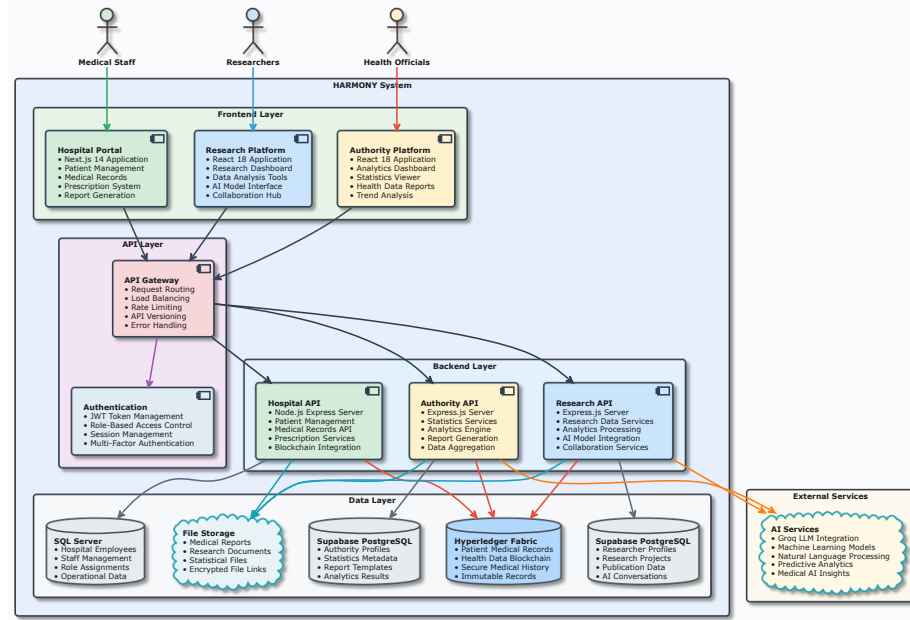


Figure 4.1: HARMONY System Architecture

4.2 Module Specific Architectures

4.2.1 Healthcare Application Module Architecture

The Healthcare Application module is designed to support secure, scalable, and real time healthcare management for medical institutions. The platform uses Next.js 14 with TypeScript for the frontend, providing a responsive and interactive user experience for medical staff. The backend leverages Node.js with Express.js, handling authentication, patient management, medical records, and integration with blockchain services.

Microsoft SQL Server serves as the primary database, supporting role based security and real time medical data processing. Cloud storage manages medical files and patient images, while Hyperledger Fabric blockchain enables immutable medical record storage and comprehensive audit trails for regulatory compliance.

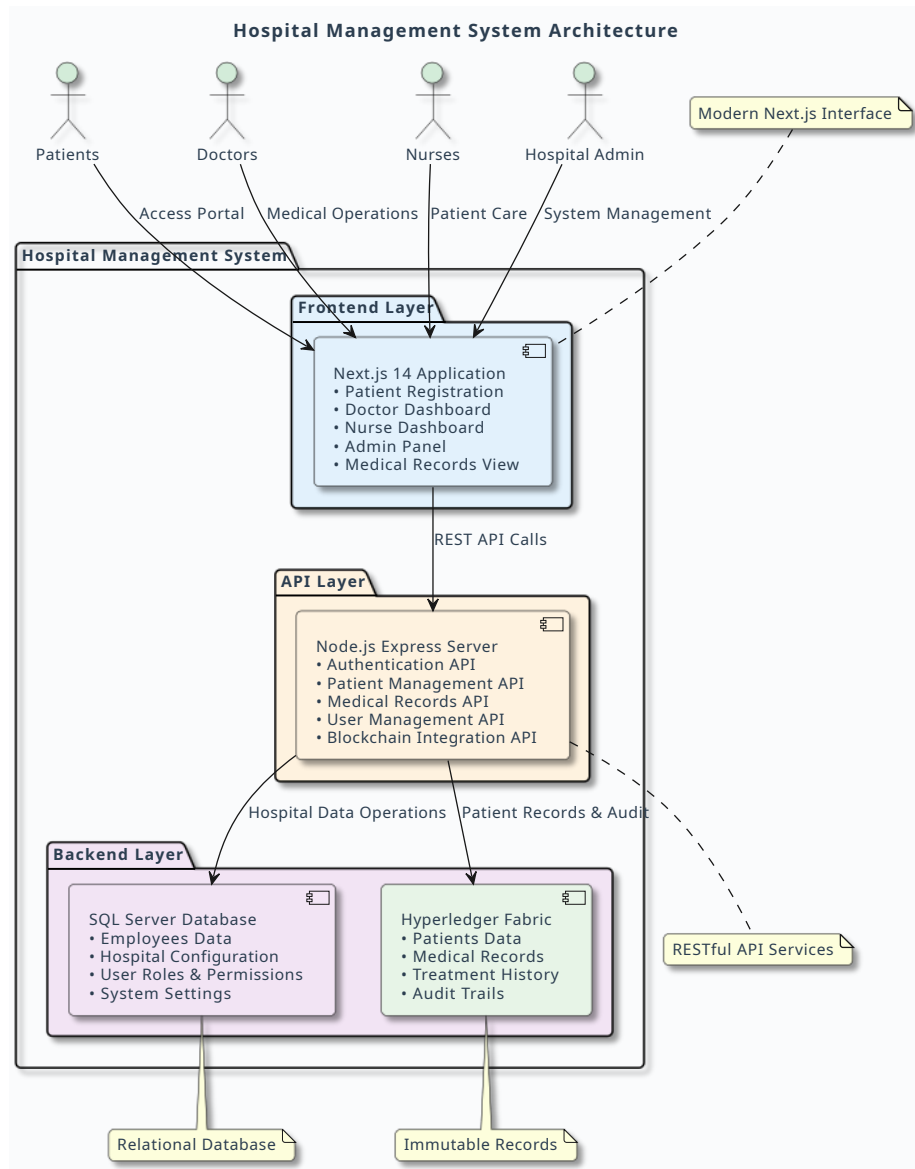


Figure 4.2: Healthcare Application Module Architecture

4.2.2 Researcher Platform Module Architecture

The Researcher Platform module architecture supports secure, scalable, and real time collaboration for medical research. Built with React 18 and TypeScript frontend, it provides an intuitive interface for research collaboration and data analysis. The Express.js backend with TypeScript handles authentication, file

uploads, messaging, and integration with AI services.

Supabase PostgreSQL serves as the primary database with row level security and real time subscriptions. Supabase Storage manages research files and avatars, while Groq and HuggingFace APIs enable advanced AI features. The blockchain medical network provides anonymized medical data for analytics and research hub functionality.

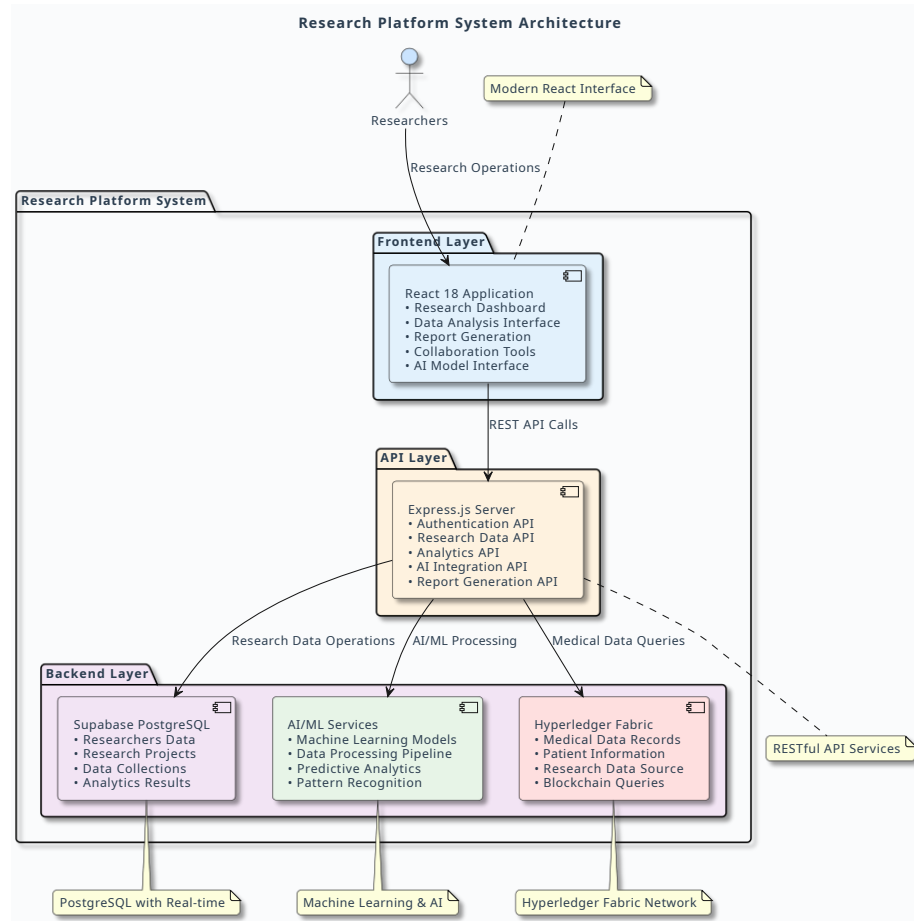


Figure 4.3: Researcher Platform Module Architecture

4.2.3 Authority Platform Module Architecture

The Authority Platform module architecture is designed to support secure, scalable, and comprehensive health data management for government health authorities. The React 18 with TypeScript frontend provides a responsive and secure interface tailored for government officials. The Express.js backend handles

government authentication, statistical file uploads, analytics processing, and blockchain health network integration.

Supabase PostgreSQL serves as the primary database with enhanced security for government operations. Supabase Storage manages statistical reports and health data files with strict regulatory compliance. Blockchain medical networks provide anonymized population health data for comprehensive analytics and trend analysis.

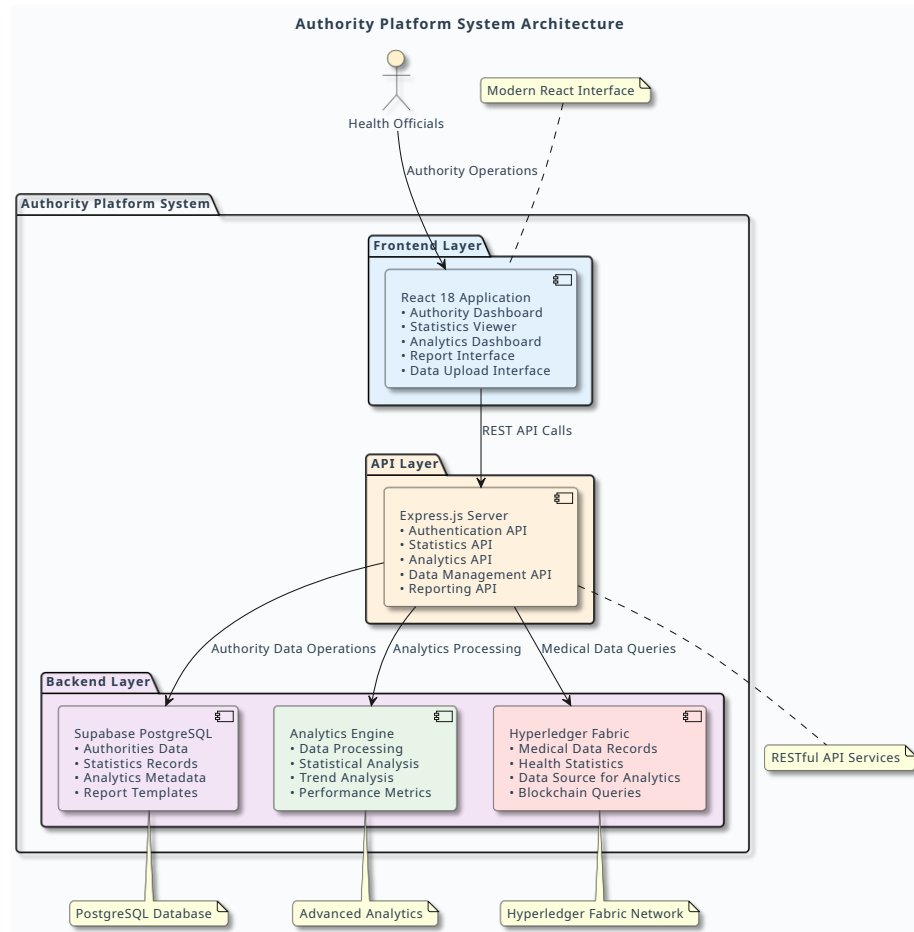


Figure 4.4: Authority Platform Module Architecture

4.3 High Level Design

The HARMONY high level design demonstrates how the three modules interact within a unified ecosystem while maintaining their specialized functions. The

design emphasizes separation of concerns, secure data flow, and integration points that enable comprehensive healthcare data lifecycle management.

4.3.1 Integrated Module Design

The high level design showcases the interconnected nature of HARMONY's three modules:

- **Healthcare Application:** Manages clinical operations with patient registration, medical records, prescription management, and vital signs monitoring. Data flows to blockchain for immutable storage and to research/authority platforms through anonymization services.
- **Researcher Platform:** Facilitates medical research collaboration with secure file sharing, AI powered analysis, real time study rooms, and population health analytics derived from anonymized clinical data.
- **Authority Platform:** Enables government health surveillance with statistical report management, blockchain powered analytics, and real time population health monitoring using aggregated data from healthcare institutions.

4.3.2 Healthcare Application High Level Design

Key modules include frontend (Next.js) for medical staff interfaces, backend (Node.js) for authentication and medical record management, Microsoft SQL Server for clinical data storage, cloud storage for medical files, and Hyperledger Fabric for blockchain integration.

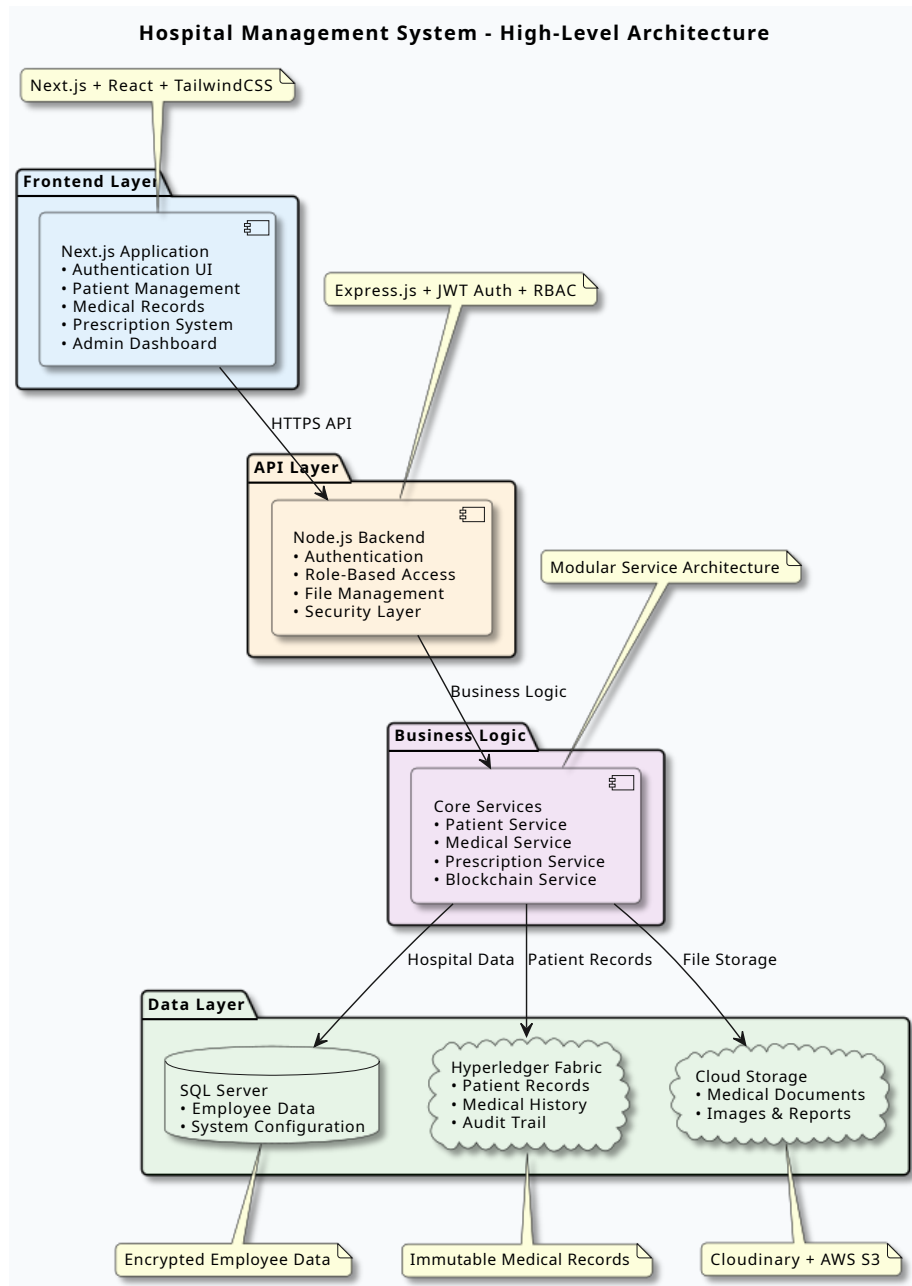


Figure 4.5: Healthcare Application High Level Design

4.3.3 Researcher Platform High Level Design

Key modules include React frontend for research interfaces, Express backend for collaboration services, Supabase PostgreSQL for research data, Supabase Storage for file management, AI services for analysis, and blockchain medical networks for anonymized data access.

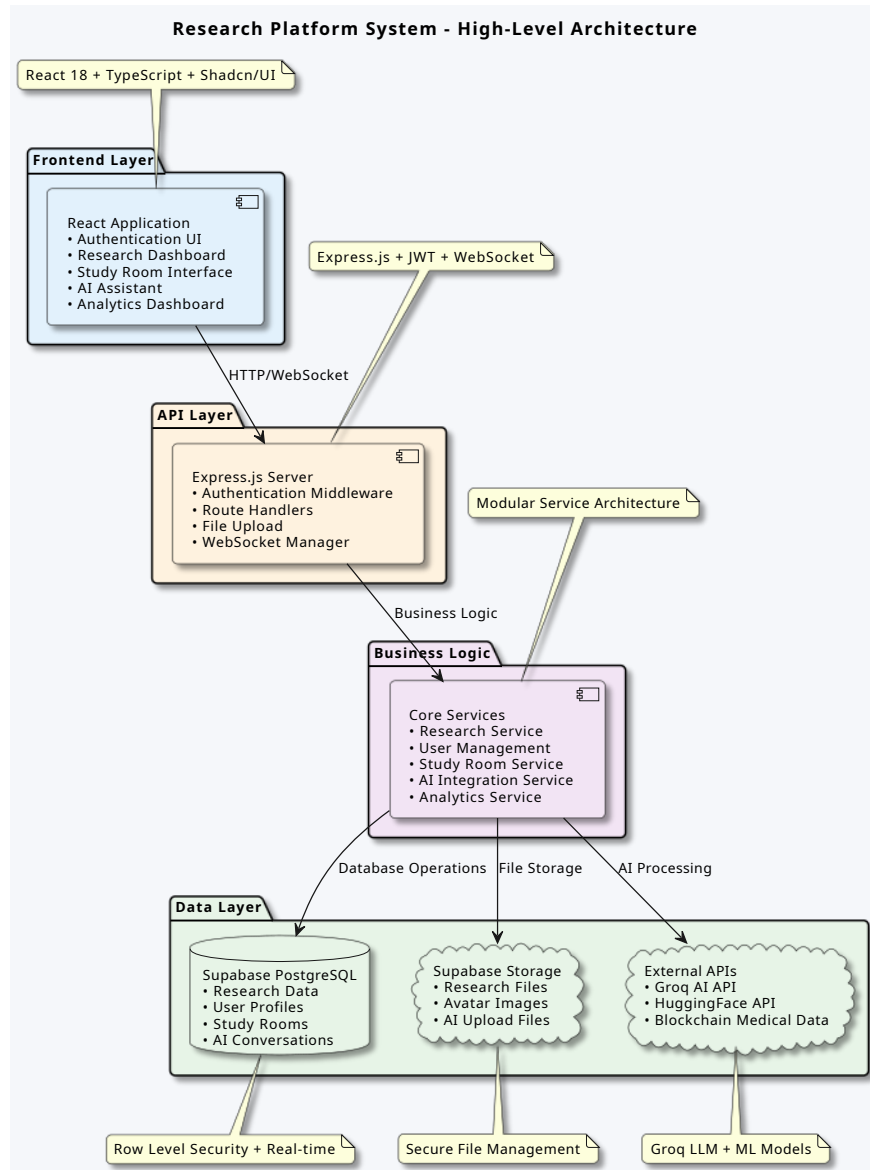


Figure 4.6: Researcher Platform High Level Design

4.3.4 Authority Platform High Level Design

Key modules include React frontend for government interfaces, Express backend for statistical management, Supabase PostgreSQL for health data storage, Supabase Storage for government documents, and blockchain health networks for population analytics.

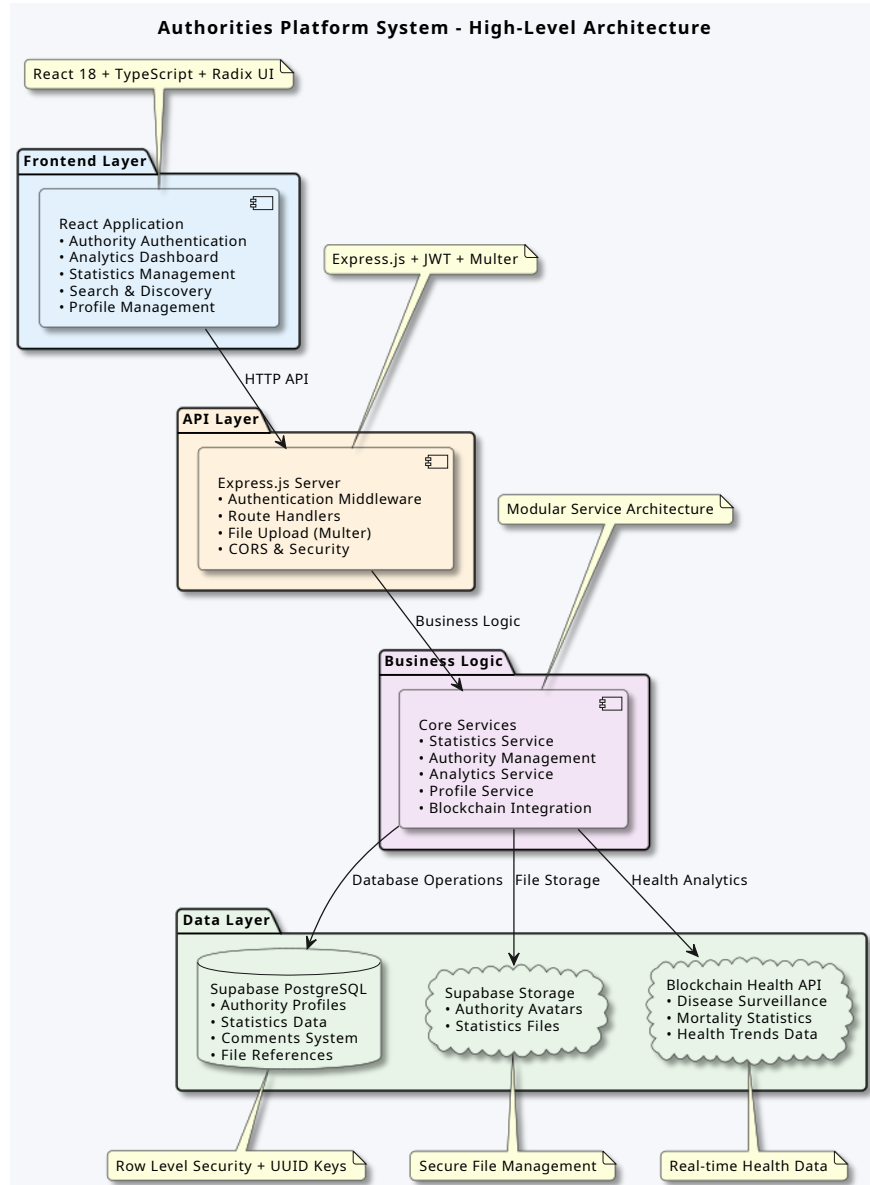


Figure 4.7: Authority Platform High Level Design

4.4 Low Level Design

The low level design details the internal structure of each module, including page layouts, middleware, API endpoints, and data models. It describes how user actions are processed, validated, and persisted across all three platforms, ensuring robust error handling, security, and cross module data consistency.

4.4.1 Healthcare Application Low Level Design

Frontend pages include authentication, admin dashboard, doctor dashboard, nurse dashboard, pharmacist dashboard, patient management, medical records, vitals monitoring, and prescription management. Backend routes are organized by medical features with middleware for authentication, validation, and blockchain integration.

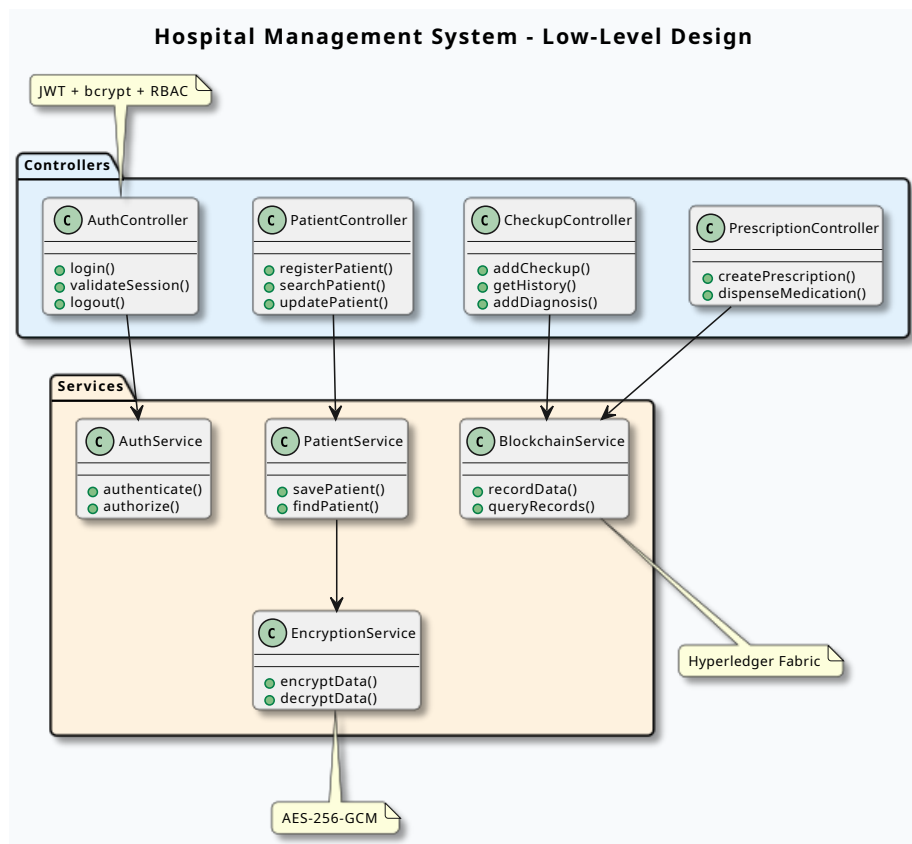


Figure 4.8: Healthcare Application Low Level Design

4.4.2 Researcher Platform Low Level Design

Frontend pages include authentication, dashboard, research upload, search, research detail, study rooms, messaging, profile edit, analytics, and research hub. Backend routes are organized by collaboration features with middleware for authentication, validation, and AI service integration.

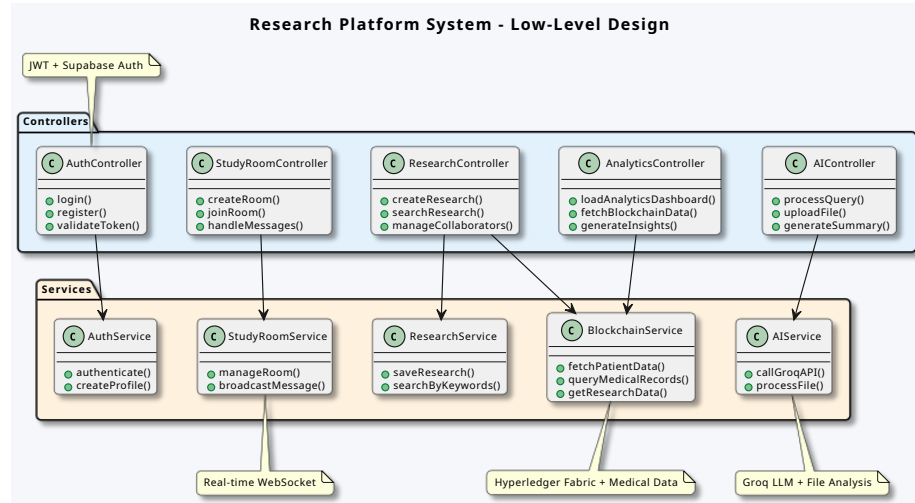


Figure 4.9: Researcher Platform Low Level Design

4.4.3 Authority Platform Low Level Design

Frontend pages include government authentication, analytics dashboard, statistical upload, health data search, statistical detail view, and profile management. Backend routes are organized by government health features with middleware for authentication, validation, and blockchain analytics integration.

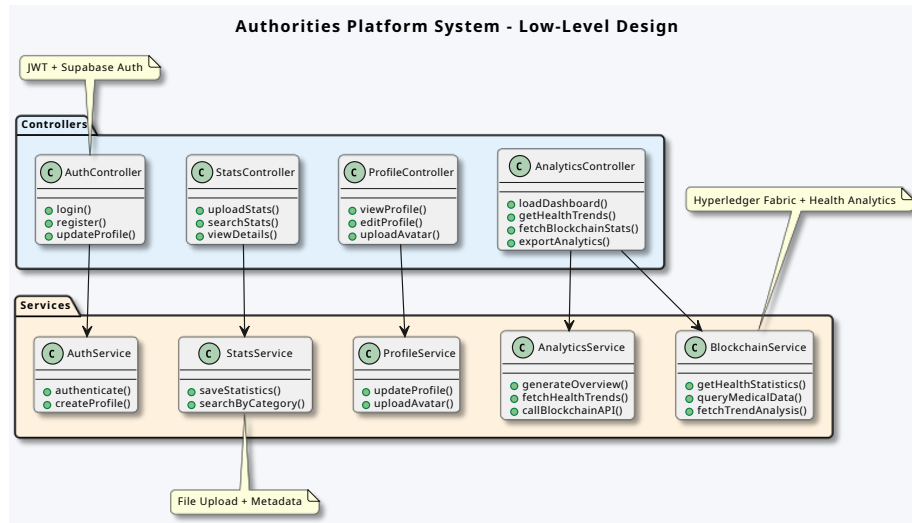


Figure 4.10: Authority Platform Low Level Design

4.5 Database Schema Design

The HARMONY ecosystem employs specialized database schemas optimized for each module's requirements while ensuring data compatibility and secure cross module access through blockchain integration and standardized APIs.

4.5.1 Healthcare Application Database Schema

The hospital database schema is designed to securely manage employee information and system access. The central employees table stores essential staff details, including personal identifiers (first name, last name), contact information (email, phone), and professional data such as designation. A robust authentication system is implemented using a unique username and a securely hashed password. Furthermore, the schema incorporates comprehensive audit logging directly within the table, tracking user action, ip address, timestamp, and status to ensure security and compliance.

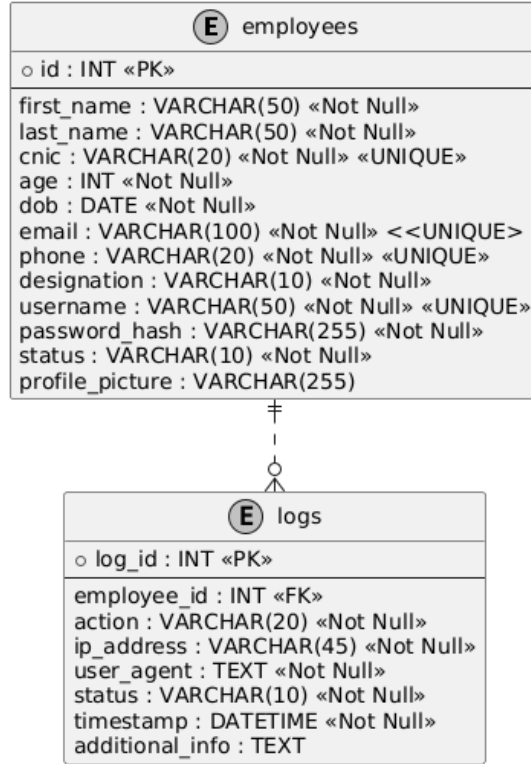


Figure 4.11: Healthcare Application Database Schema

4.5.2 Researcher Platform Database Schema

The research database schema uses Supabase PostgreSQL with row level security for user profiles, research data, collaboration, and analytics. Key tables include User (authentication), Research (metadata and files), Study Room (collaboration spaces), Message (real time communication), Comment (research discussions), AI Conversation (analysis history), and Analytics (population health data). Storage buckets manage research files and avatars.

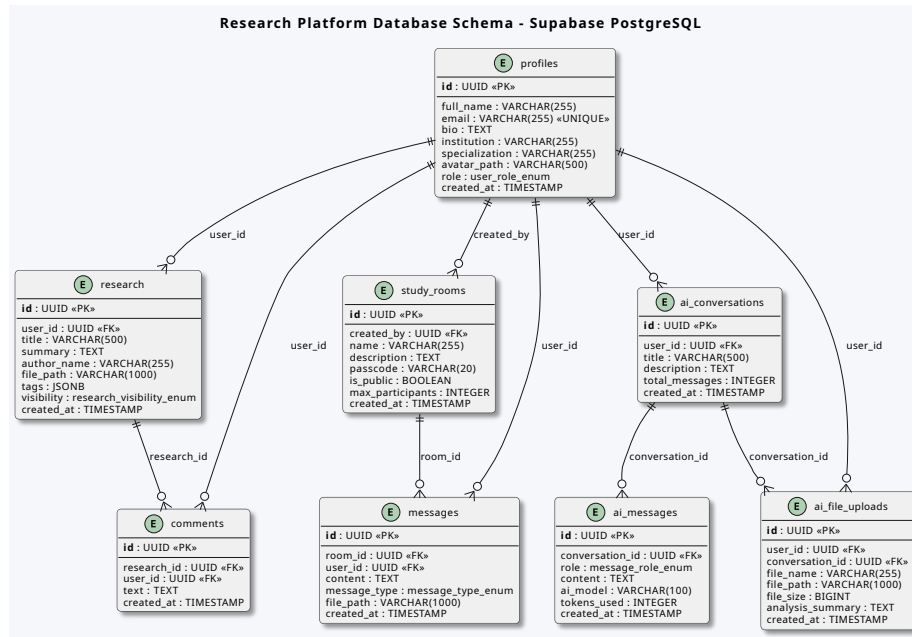


Figure 4.12: Researcher Platform Database Schema

4.5.3 Authority Platform Database Schema

The authority database schema uses Supabase PostgreSQL with enhanced government security for health statistics and analytics. Key tables include Authority (government authentication), Statistics (health report metadata), Health Analytics (population trends), Comments (statistical reviews), and Blockchain Health Data (network interactions). Storage buckets manage statistical reports and government documents with regulatory compliance.

Authorities Platform Database Schema - Supabase PostgreSQL

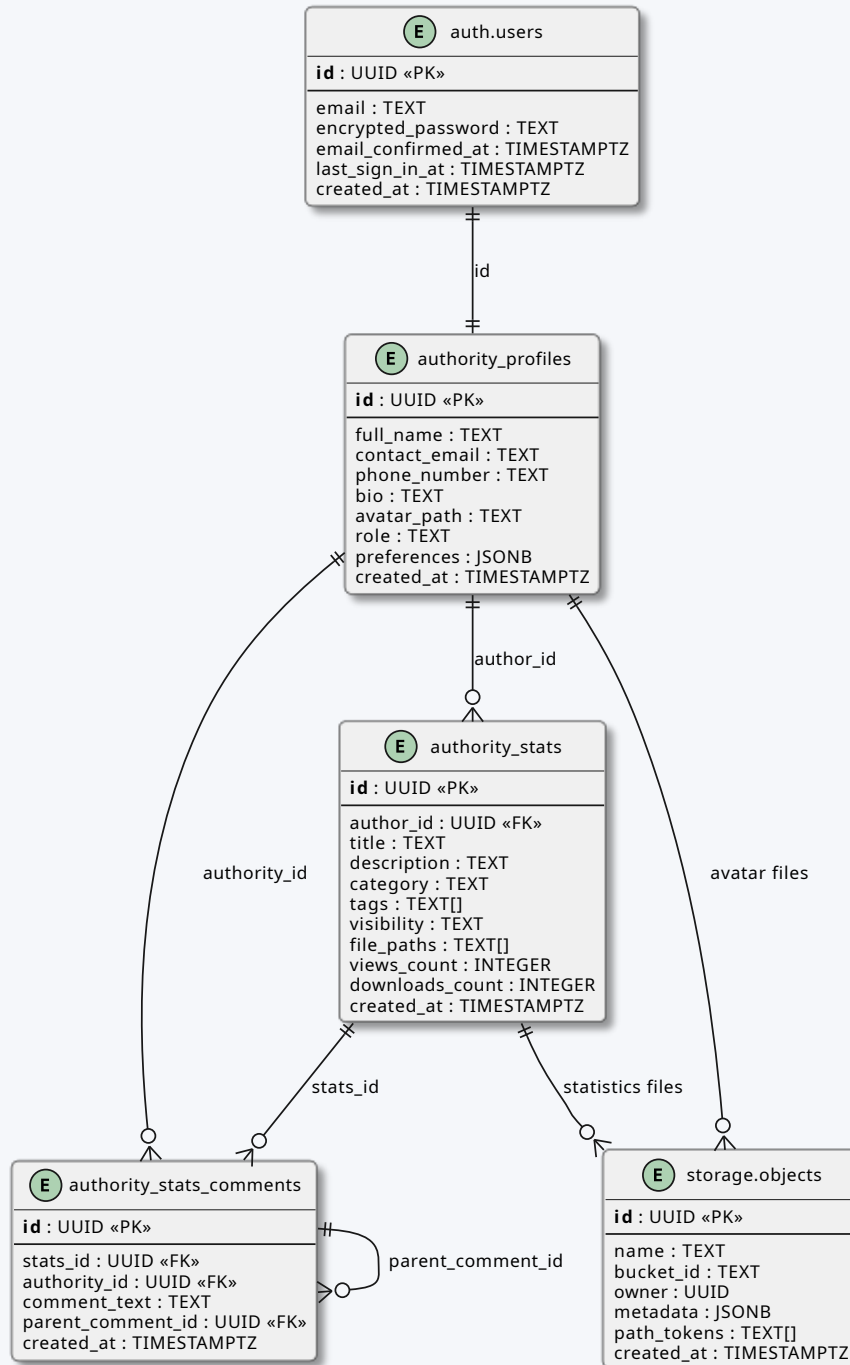


Figure 4.13: Authority Platform Database Schema

4.6 System Sequence Diagrams (SSDs)

System Sequence Diagrams (SSDs) illustrate the dynamic behavior of the HARMONY ecosystem for key interactions across all three modules. These diagrams detail the sequence of messages exchanged between actors and system components, clarifying the flow of control and data throughout the integrated healthcare platform.

4.6.1 Healthcare Application SSDs

The Healthcare Application SSDs demonstrate clinical workflows including employee authentication, patient registration, medical checkups, prescription management, vital signs monitoring, and medical record access.

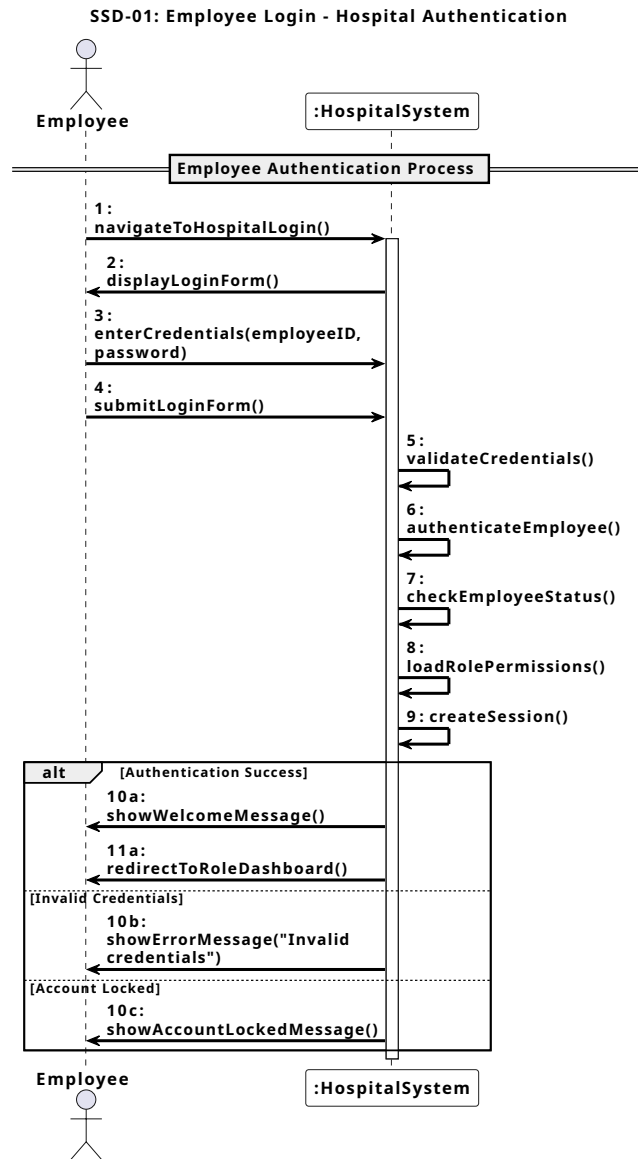


Figure 4.14: Healthcare Application - Employee Login SSD

SSD-02: Patient Registration - Patient Enrollment

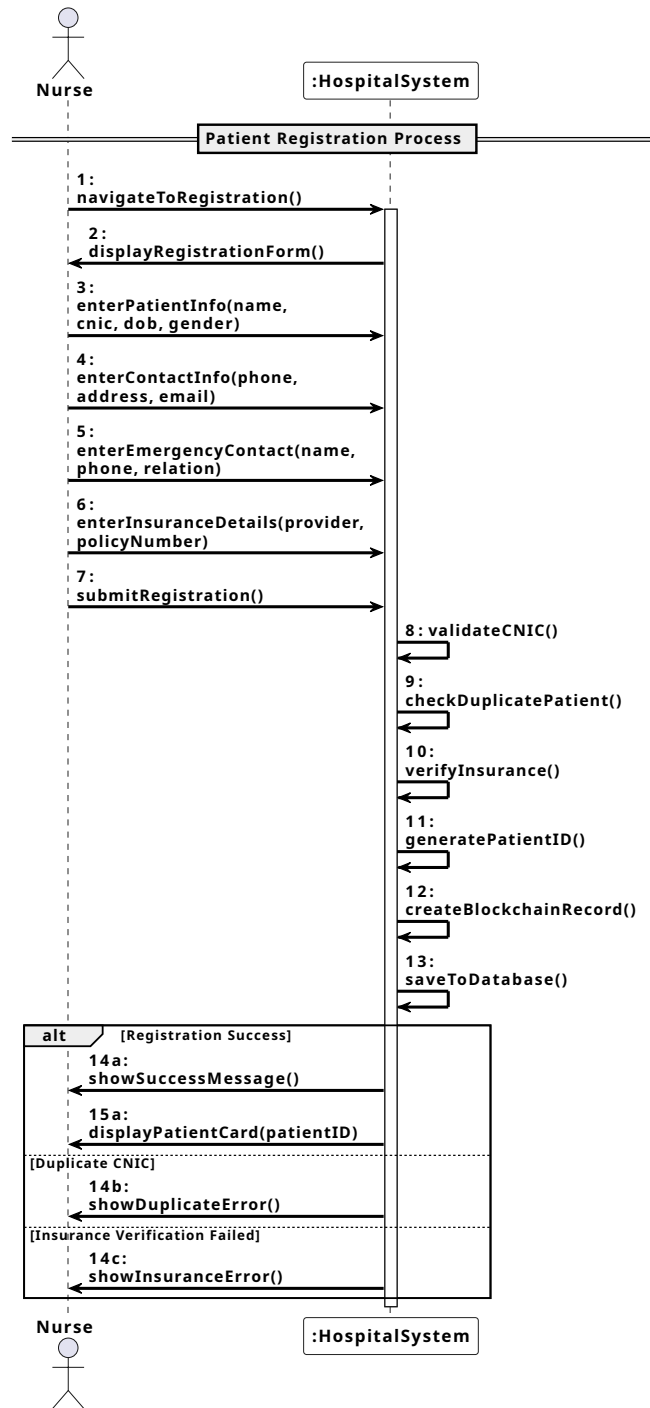


Figure 4.15: Healthcare Application - Patient Registration SSD

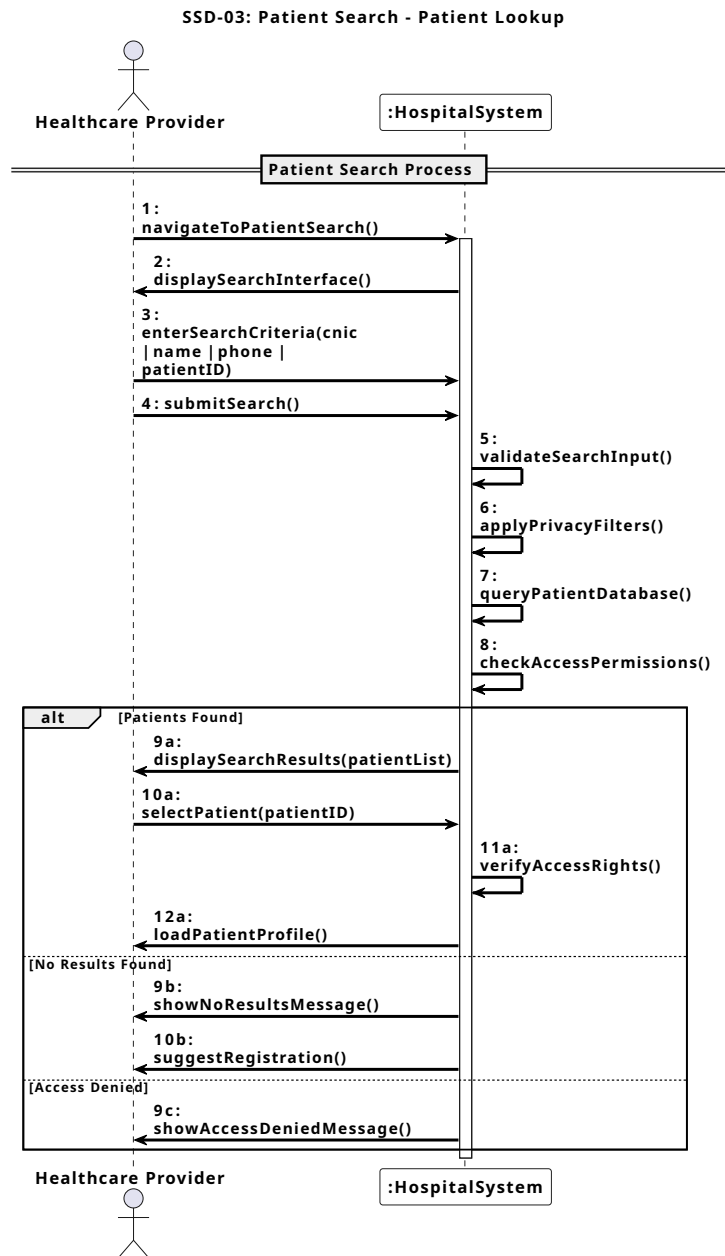


Figure 4.16: Healthcare Application - Patient Search SSD

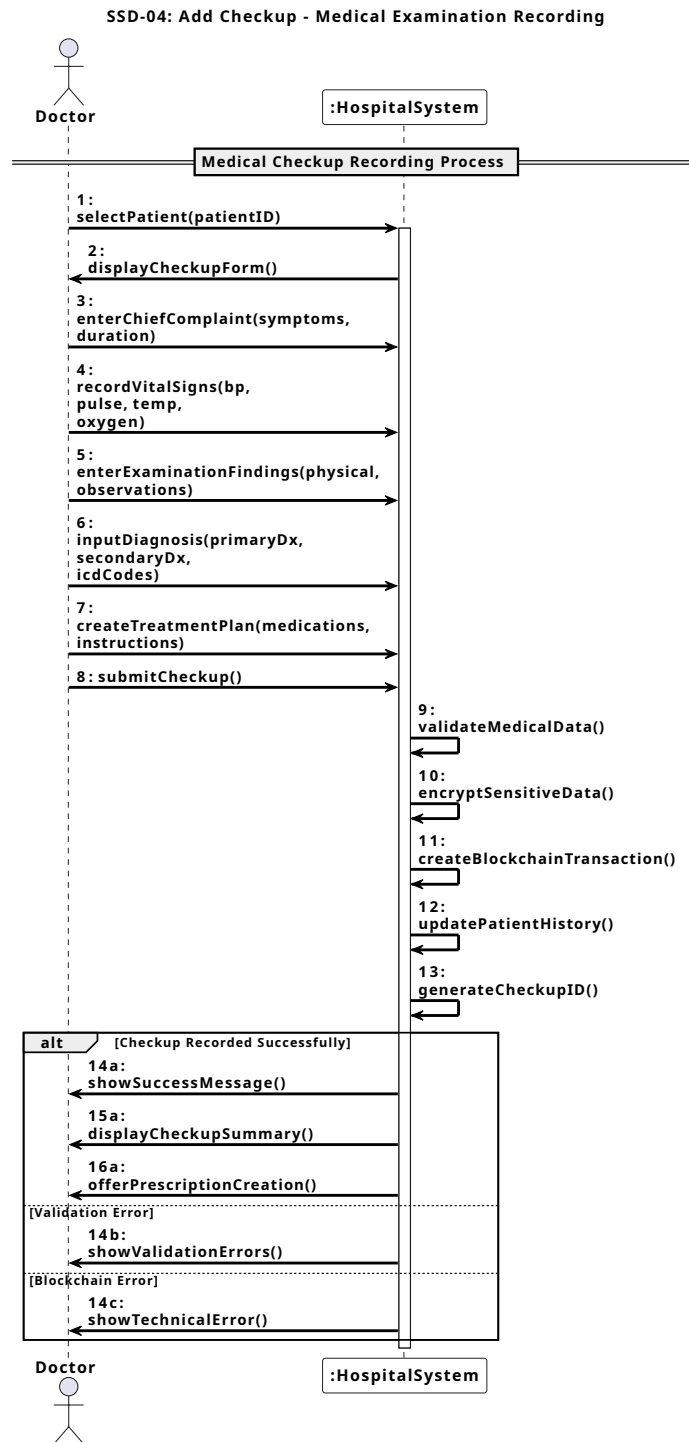


Figure 4.17: Healthcare Application - Patient Checkup SSD

SSD-05: Add Prescription - Digital Prescription Creation

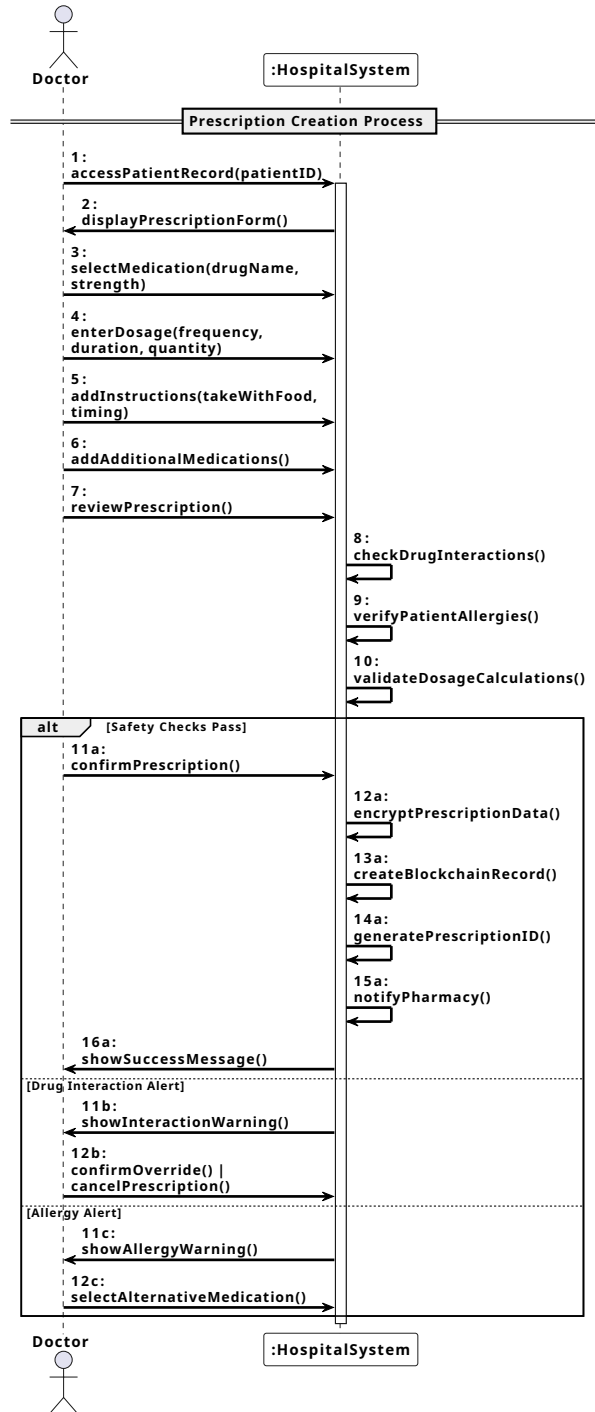


Figure 4.18: Healthcare Application - Add Prescription SSD

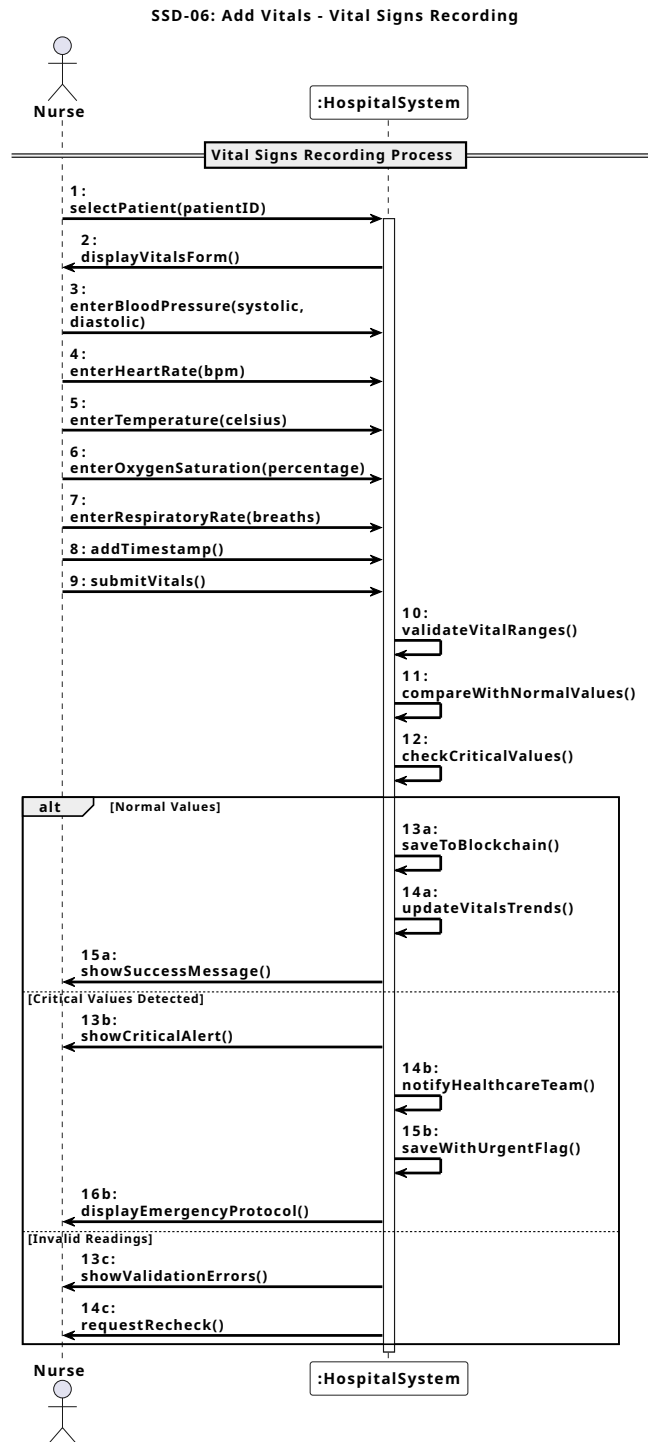


Figure 4.19: Healthcare Application - Add Vitals SSD

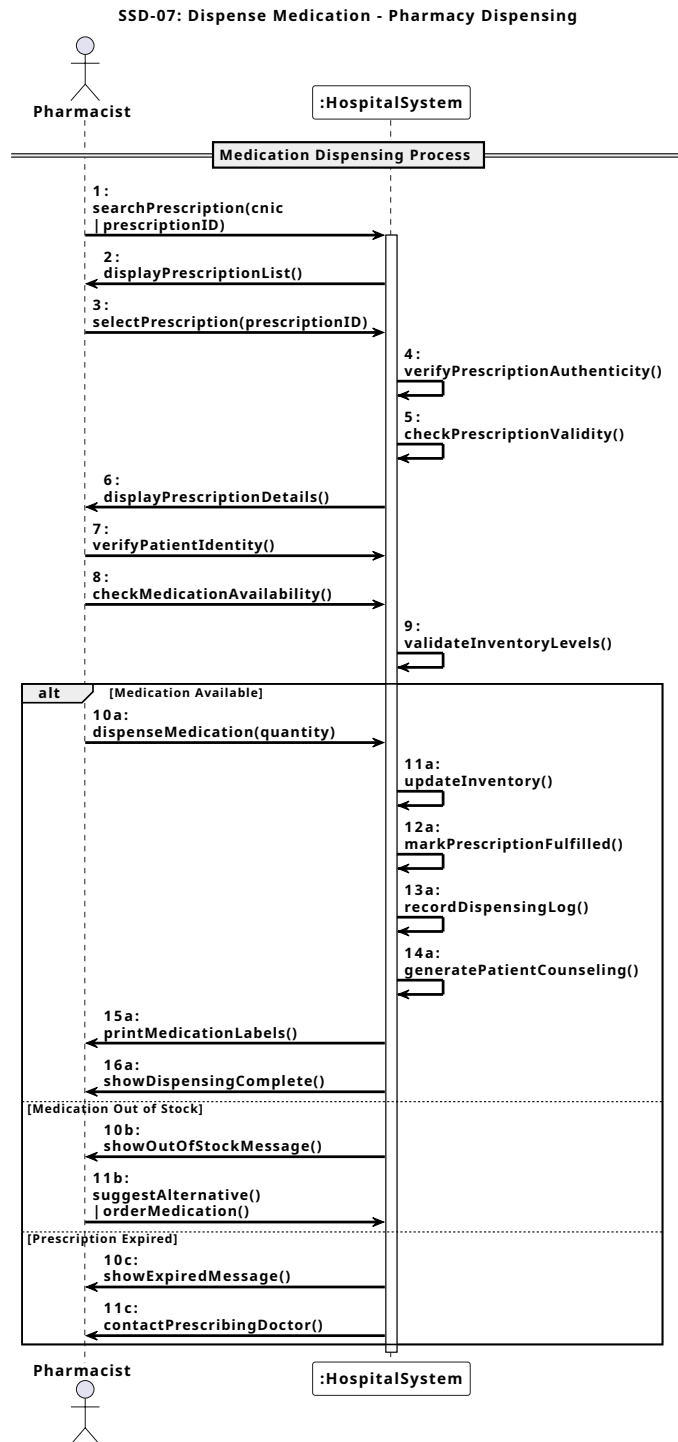


Figure 4.20: Healthcare Application - Dispensing Medication SSD

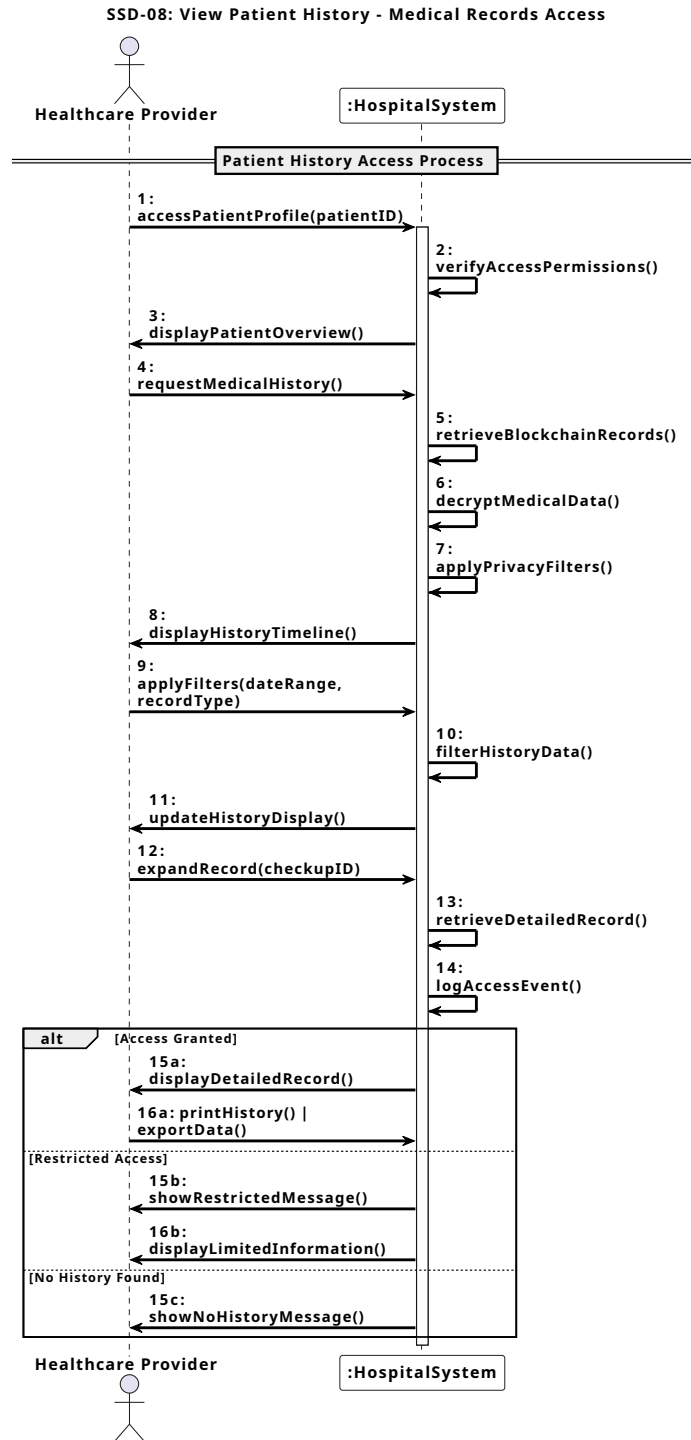


Figure 4.21: Healthcare Application - View Patient History SSD

SSD-09: Medical Report Upload - Document Management

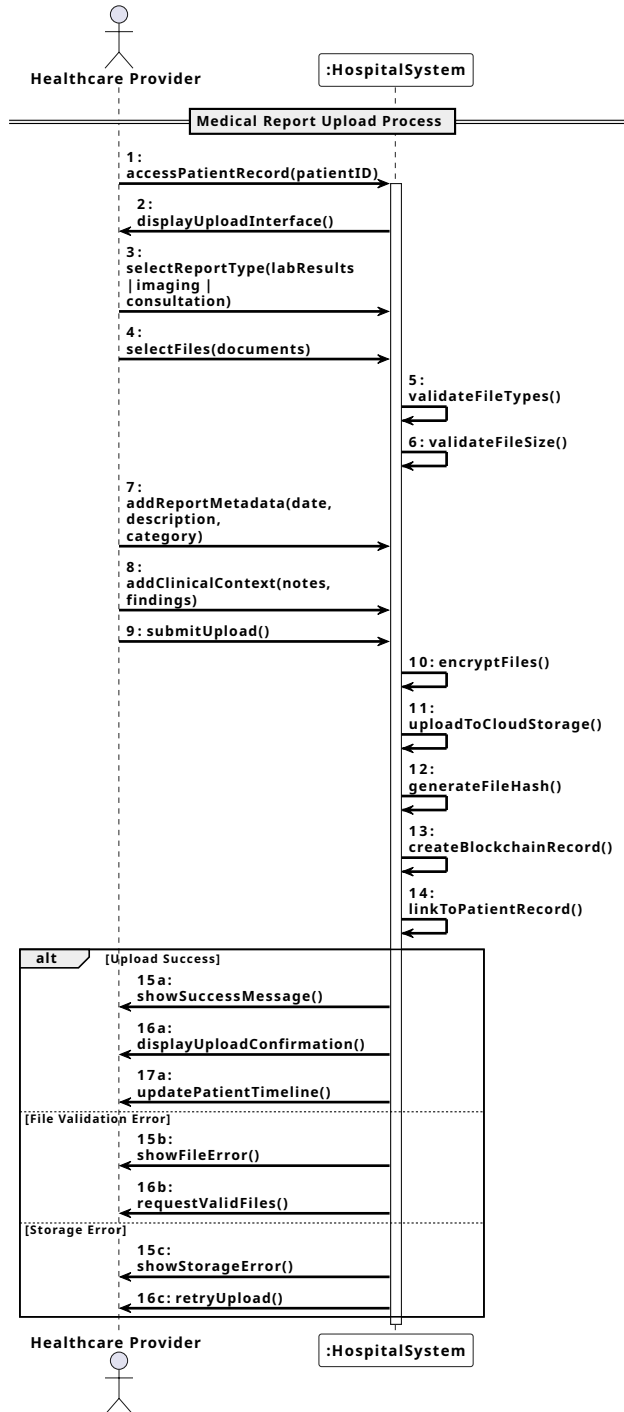


Figure 4.22: Healthcare Application - Medical History SSD

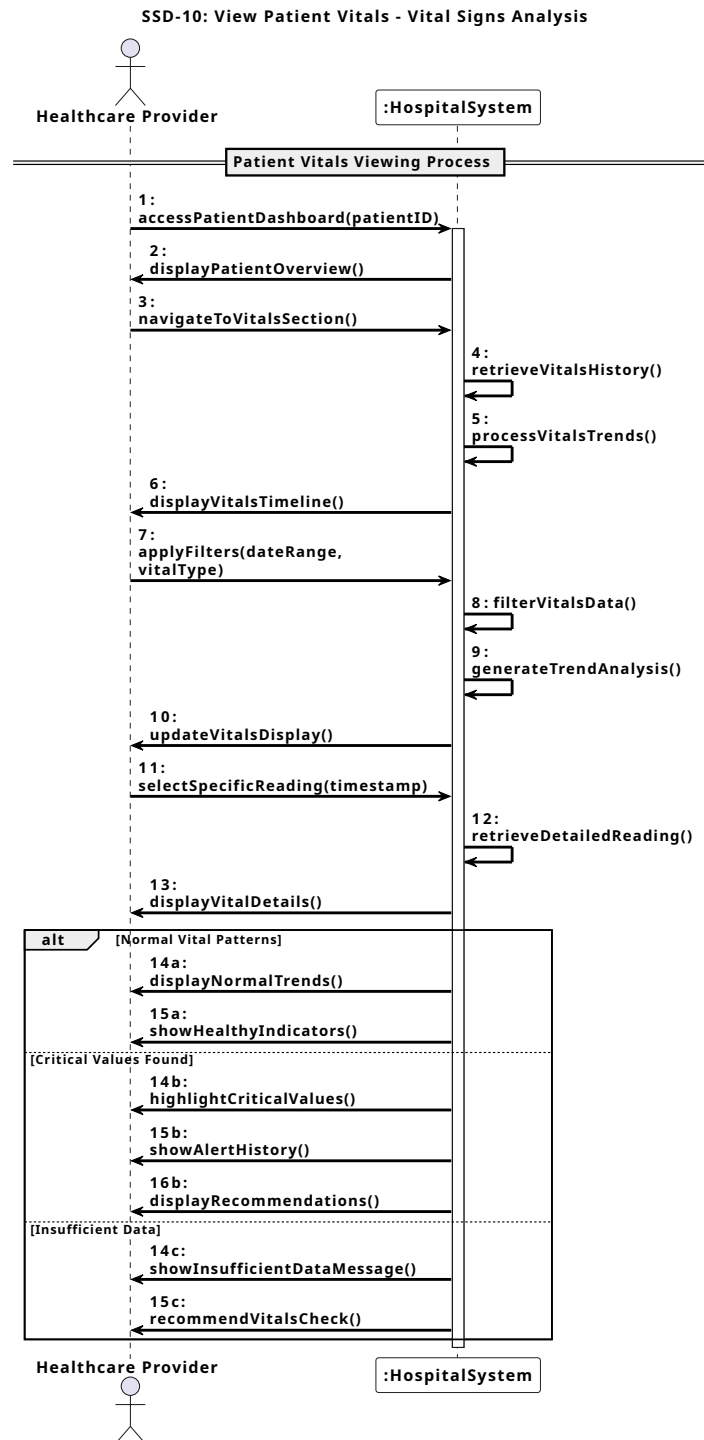


Figure 4.23: Healthcare Application - Vitals Monitoring SSD

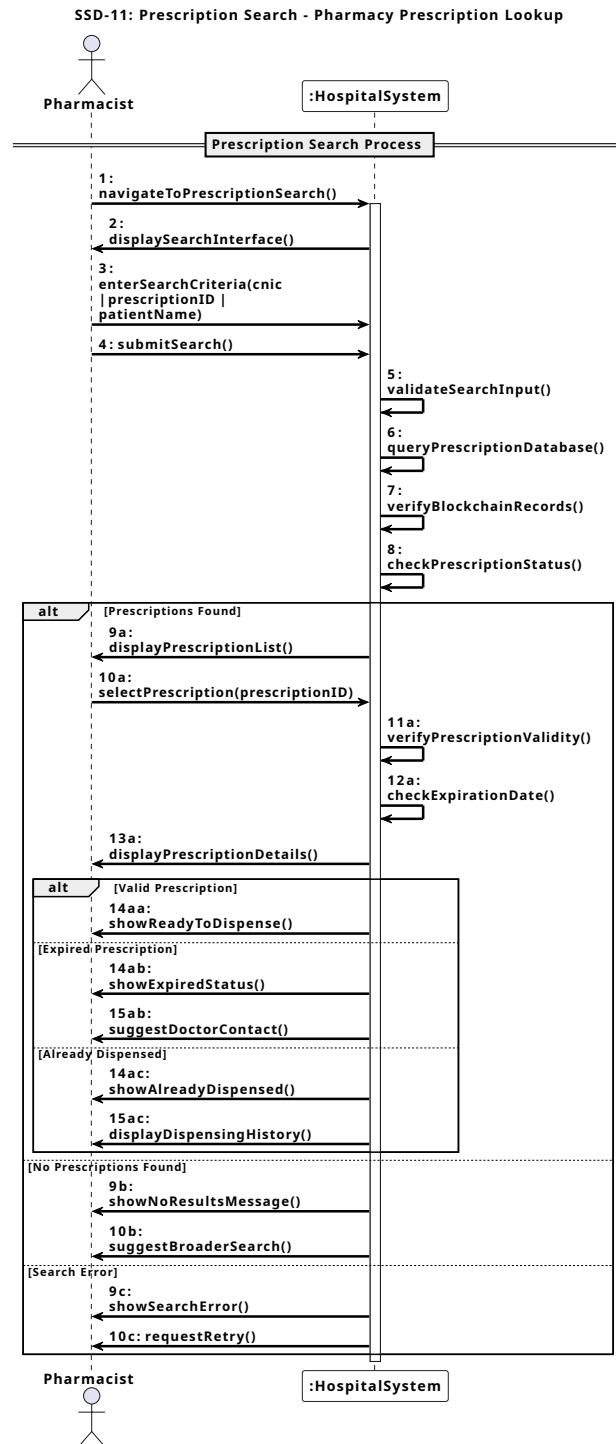


Figure 4.24: Healthcare Application - Prescription Search SSD

4.6.2 Researcher Platform SSDs

The Researcher Platform SSDs demonstrate research collaboration workflows including user authentication, research upload and sharing, AI-powered analysis, study room collaboration, and population health analytics.



Figure 4.25: Researcher Platform - Signup SSD

SSD-02: User Login - Authentication

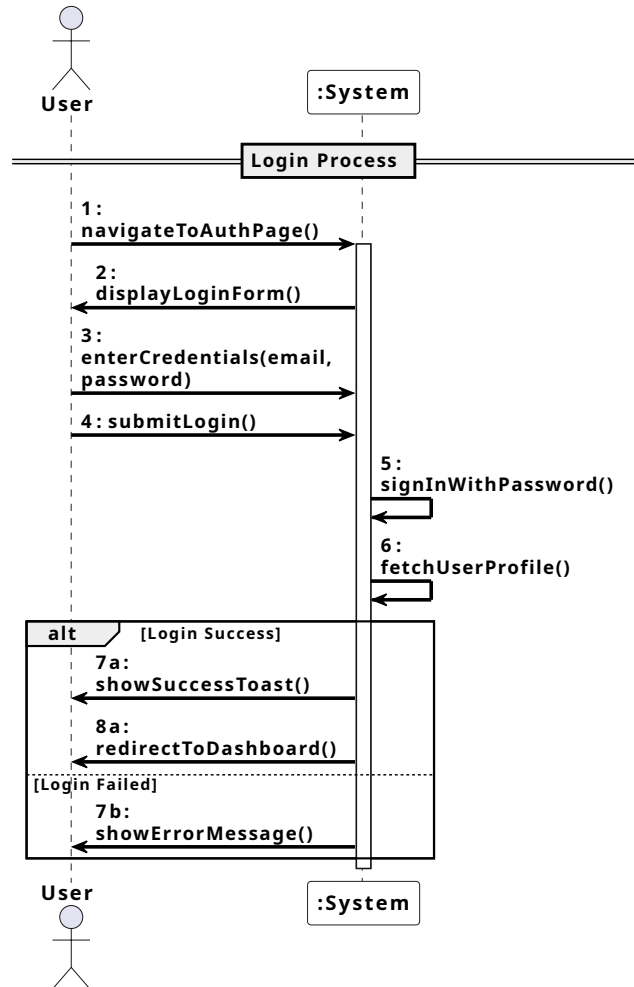


Figure 4.26: Researcher Platform - Login SSD

SSD-03: Edit Profile - User Profile Management

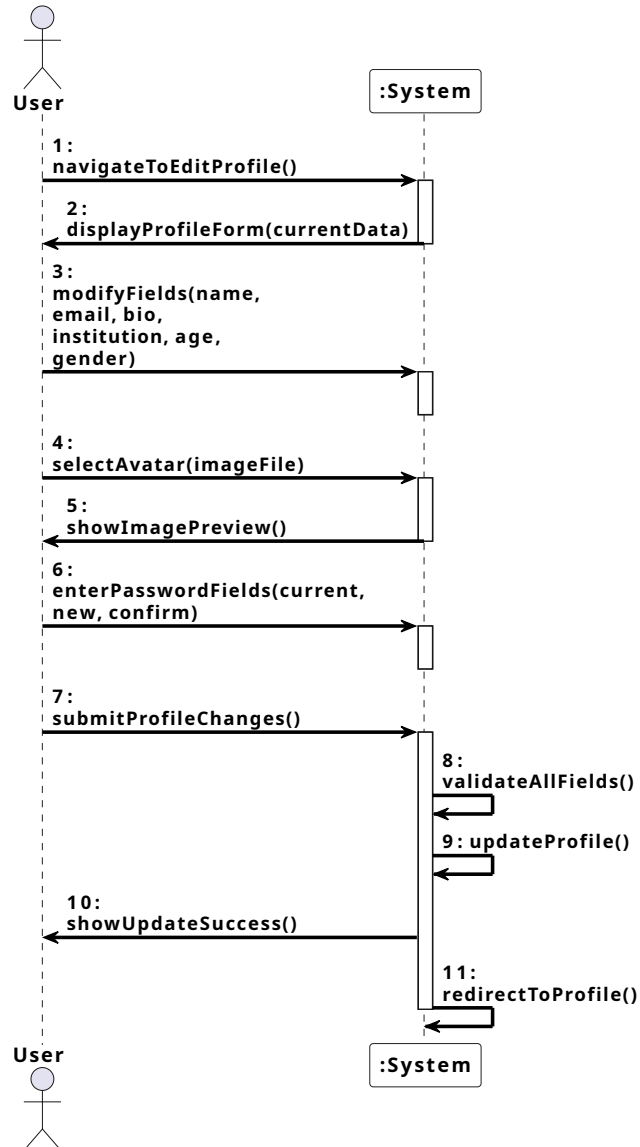


Figure 4.27: Researcher Platform - Profile Edit SSD

SSD-04: Upload Research - Research Publication Process

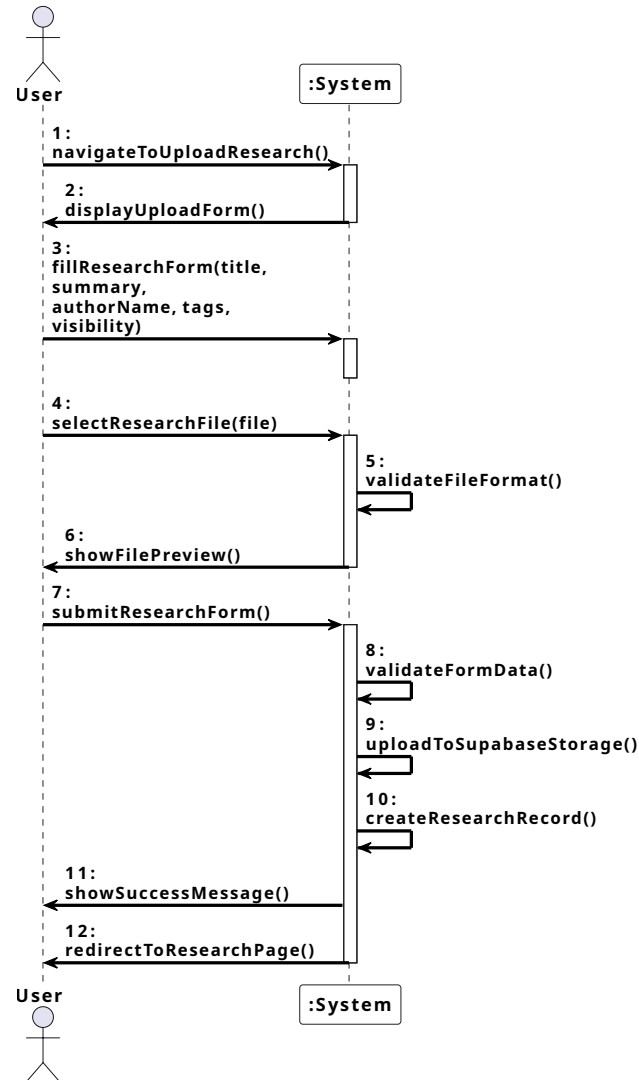


Figure 4.28: Researcher Platform - Upload Research SSD

SSD-05: Search Research - Research Discovery Process

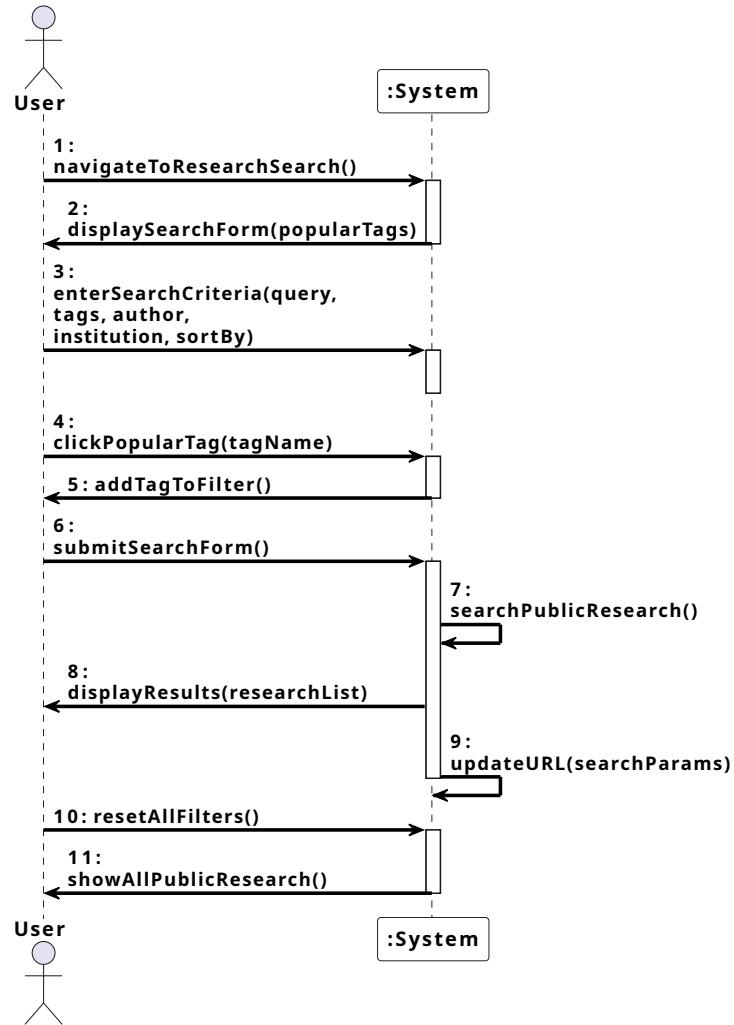


Figure 4.29: Researcher Platform - Research Search SSD

SSD-06: View Research & Download - Research Access Process

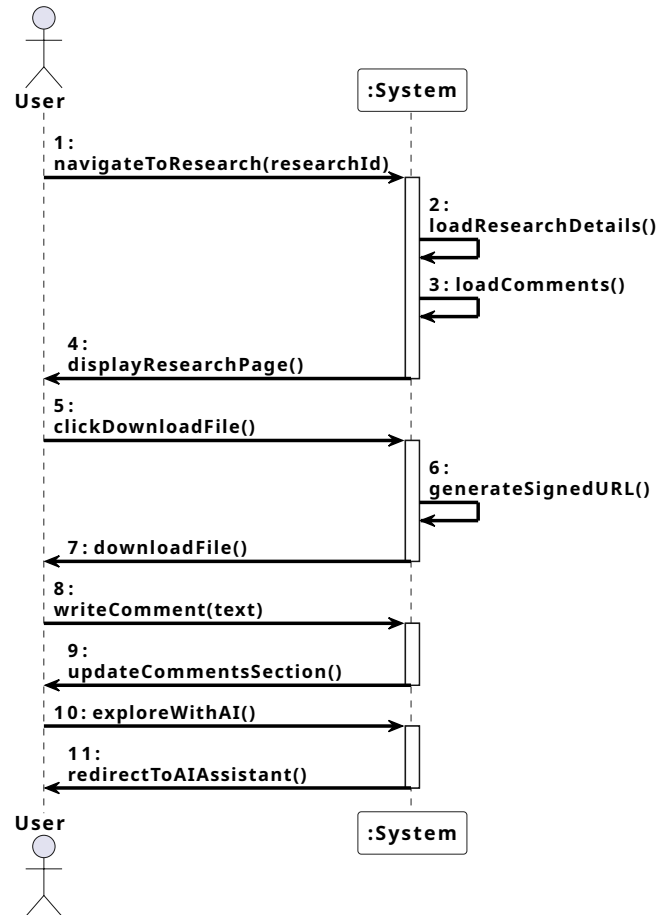


Figure 4.30: Researcher Platform - View Research SSD

SSD-07: Research Comments - Discussion Interface

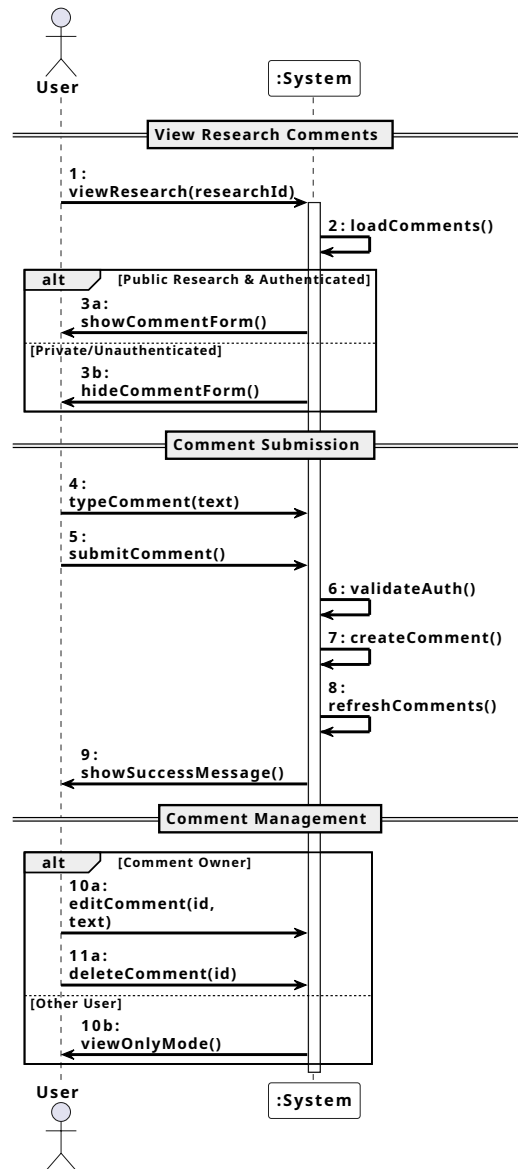


Figure 4.31: Researcher Platform - Comments SSD

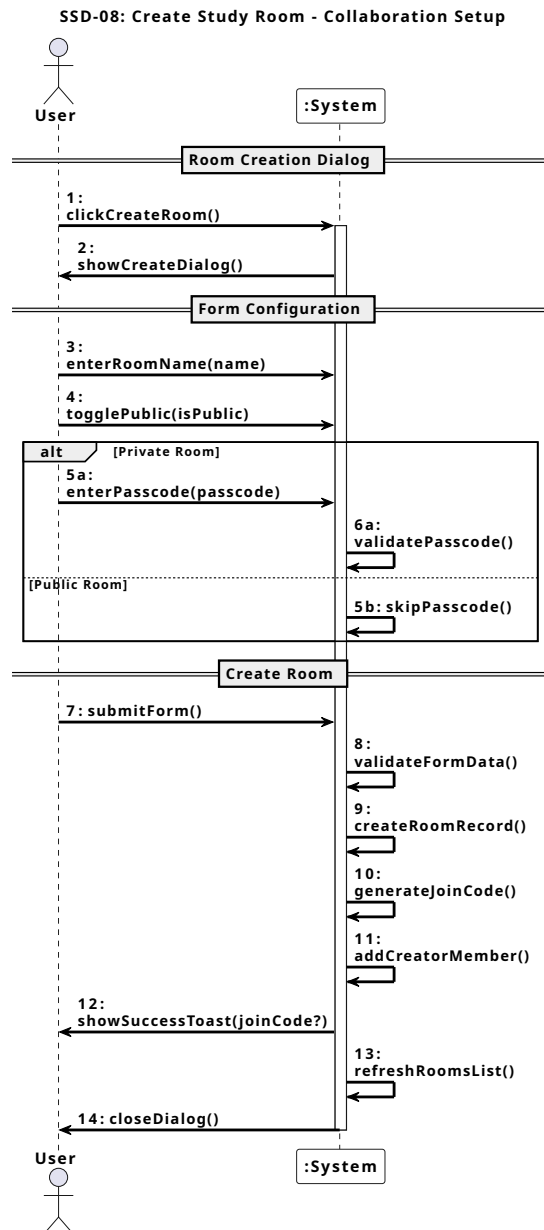


Figure 4.32: Researcher Platform - Create Study Room SSD

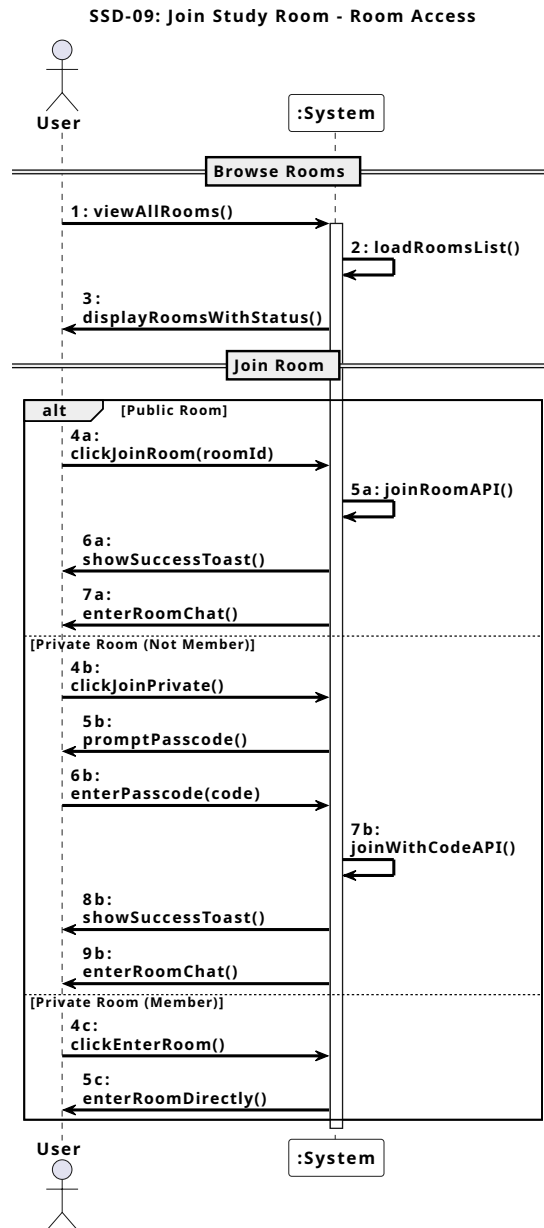


Figure 4.33: Researcher Platform - Join Study Room SSD

SSD-10: Study Room Messaging - Real-time Communication

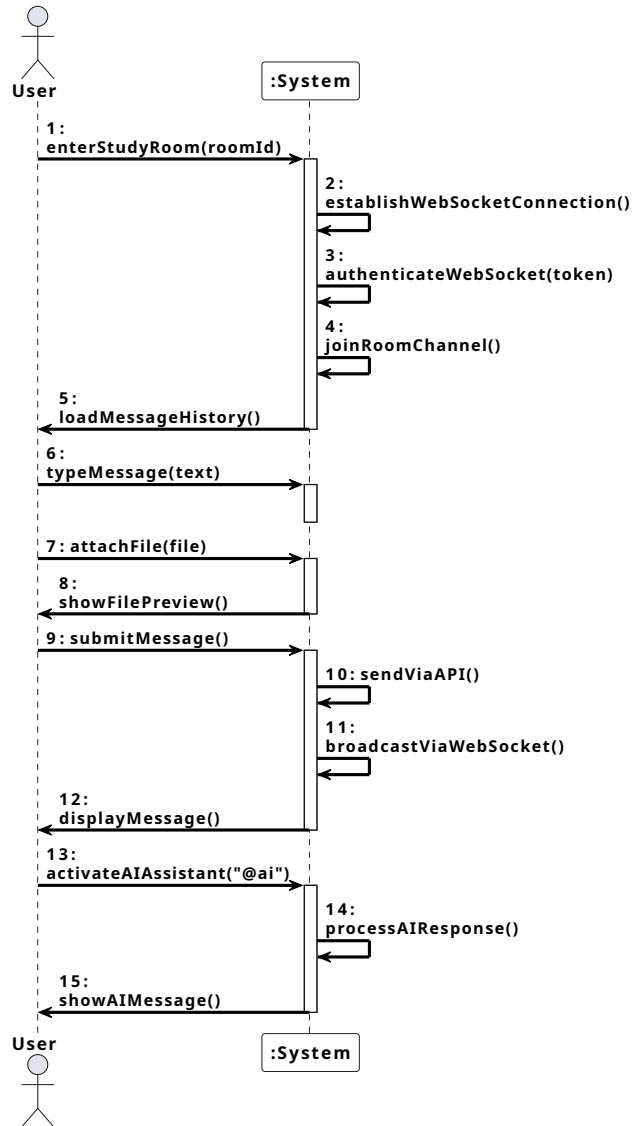


Figure 4.34: Researcher Platform - Study Room Message SSD

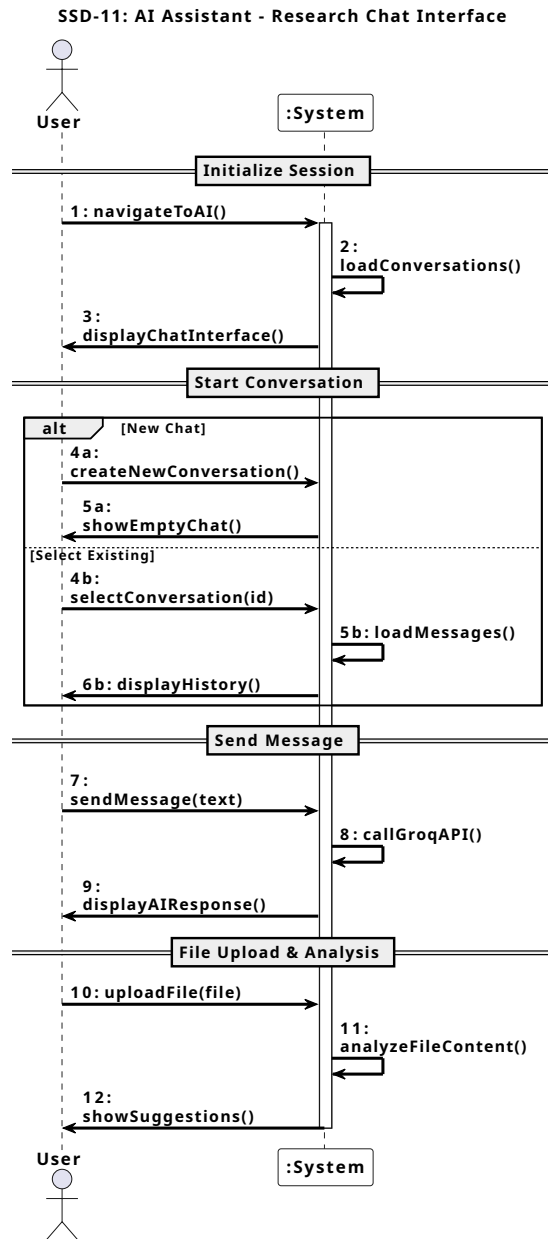


Figure 4.35: Researcher Platform - AI Assistant SSD

SSD-12: Dashboard - Personalized Analytics Interface

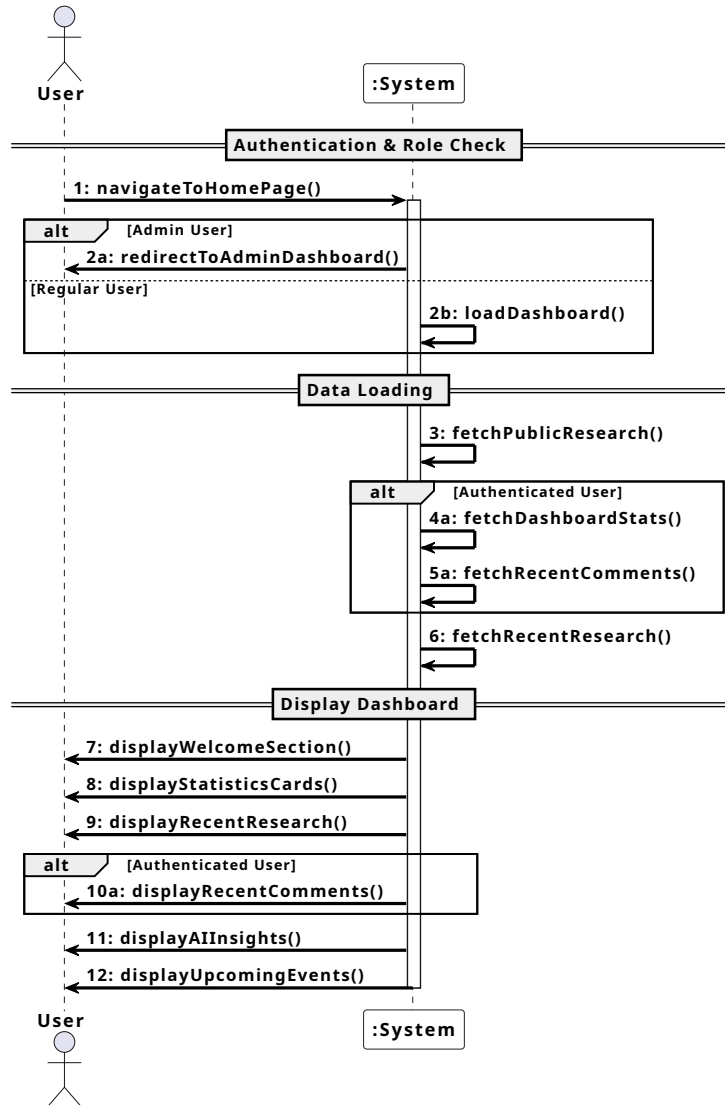


Figure 4.36: Researcher Platform - Dashboard SSD

SSD-13: Research Hub - Blockchain Medical Analytics

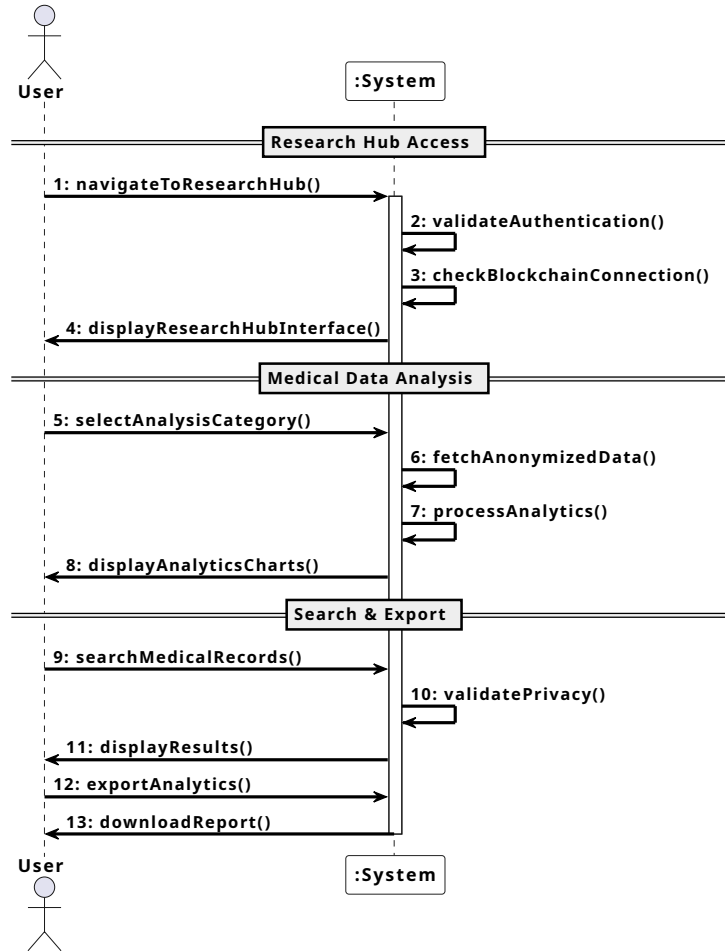


Figure 4.37: Researcher Platform - Research Hub SSD

SSD-14: Analytics Dashboard\nPopulation Health Analytics

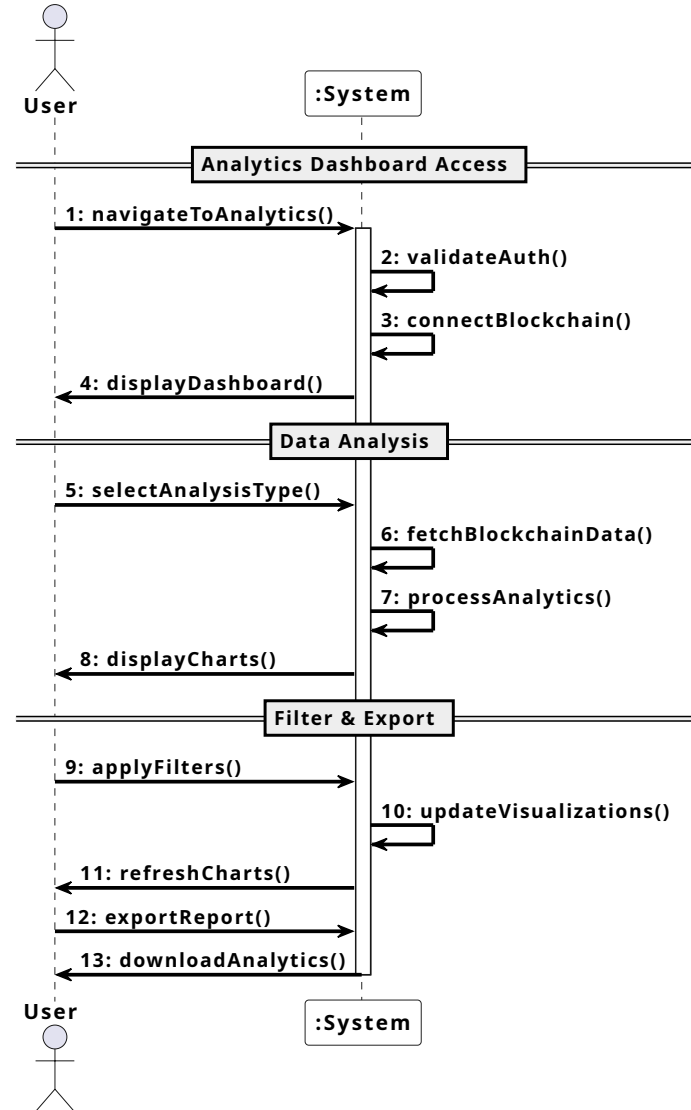


Figure 4.38: Researcher Platform - Analytics SSD

4.6.3 Authority Platform SSDs

The Authority Platform SSDs demonstrate government health surveillance workflows including authority authentication, statistical report management, health analytics dashboard, and population health monitoring.

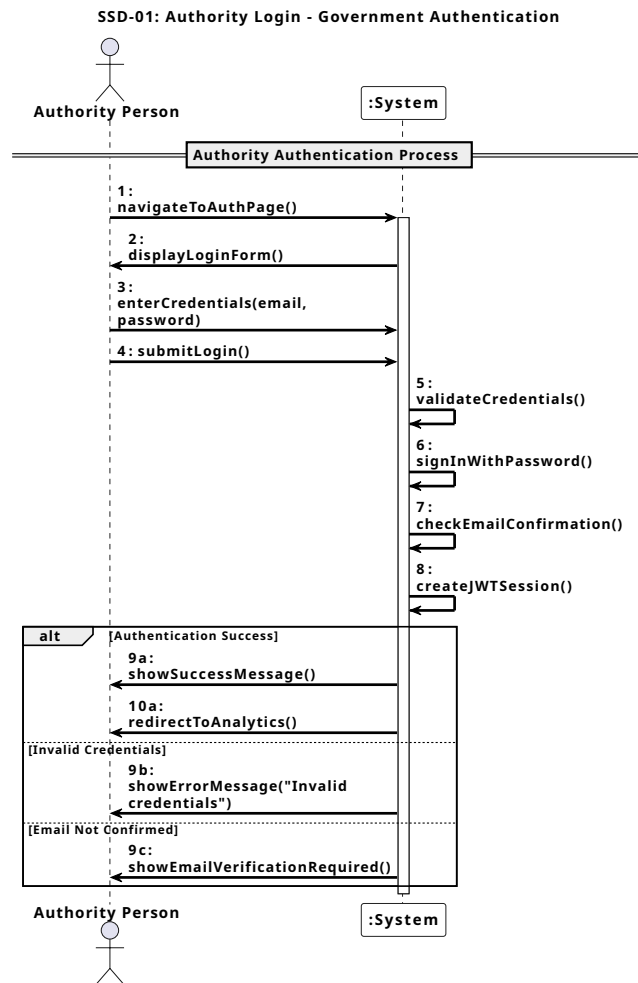


Figure 4.39: Authority Platform - Authority Login SSD

SSD-02: Statistics Upload - Health Data Submission

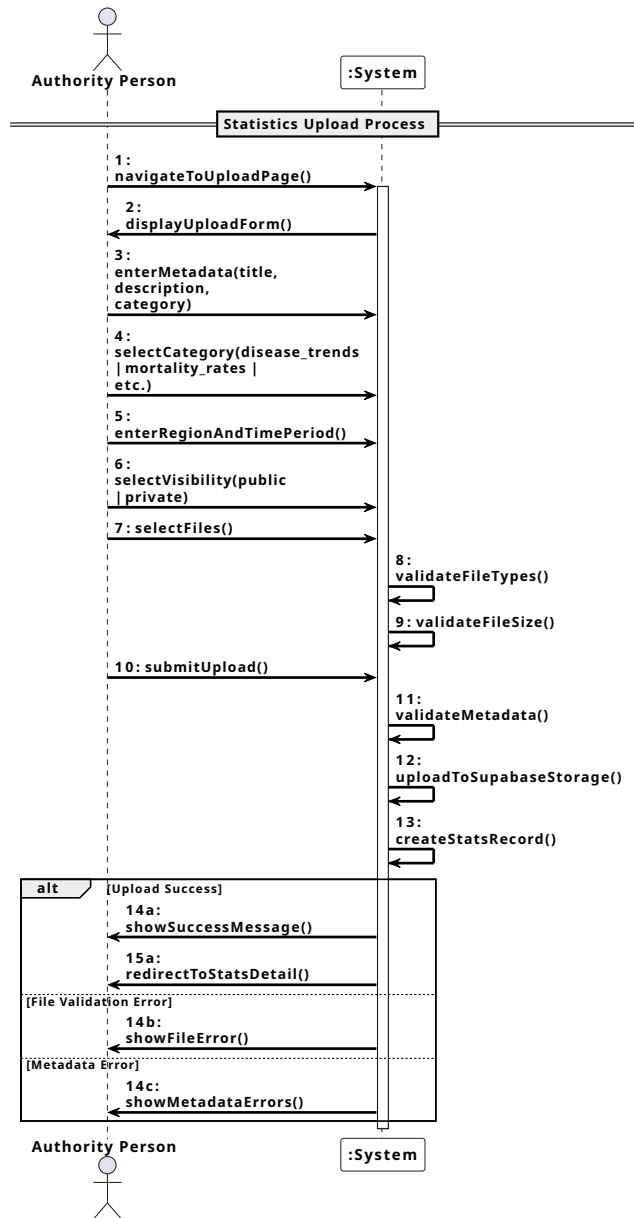


Figure 4.40: Authority Platform - Statistics Upload SSD

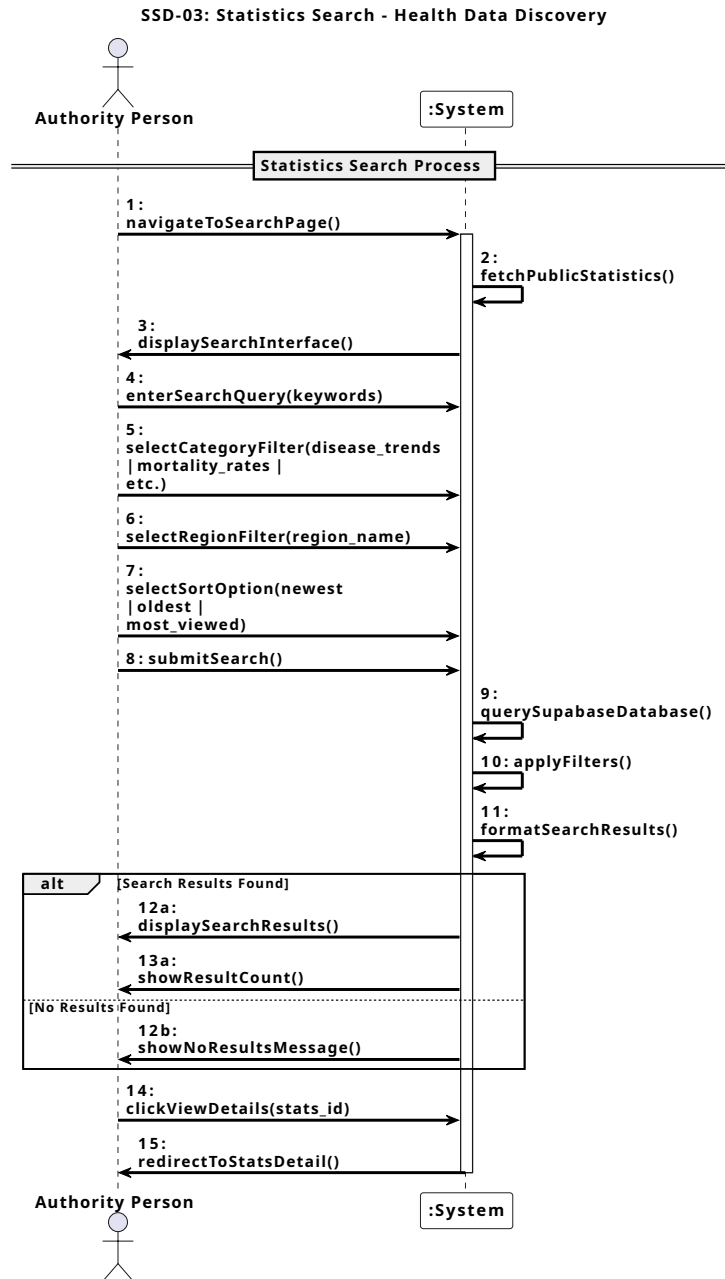


Figure 4.41: Authority Platform - Statistics Search SSD

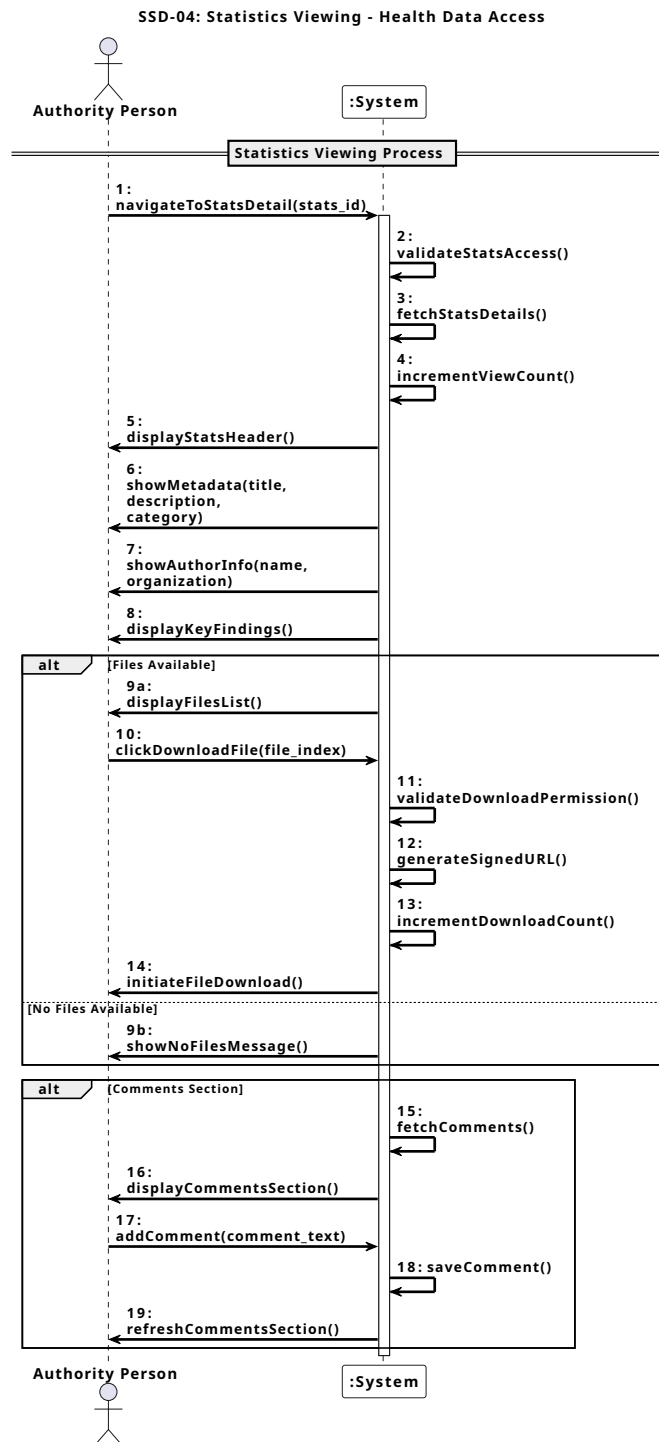


Figure 4.42: Authority Platform - Statistics View SSD

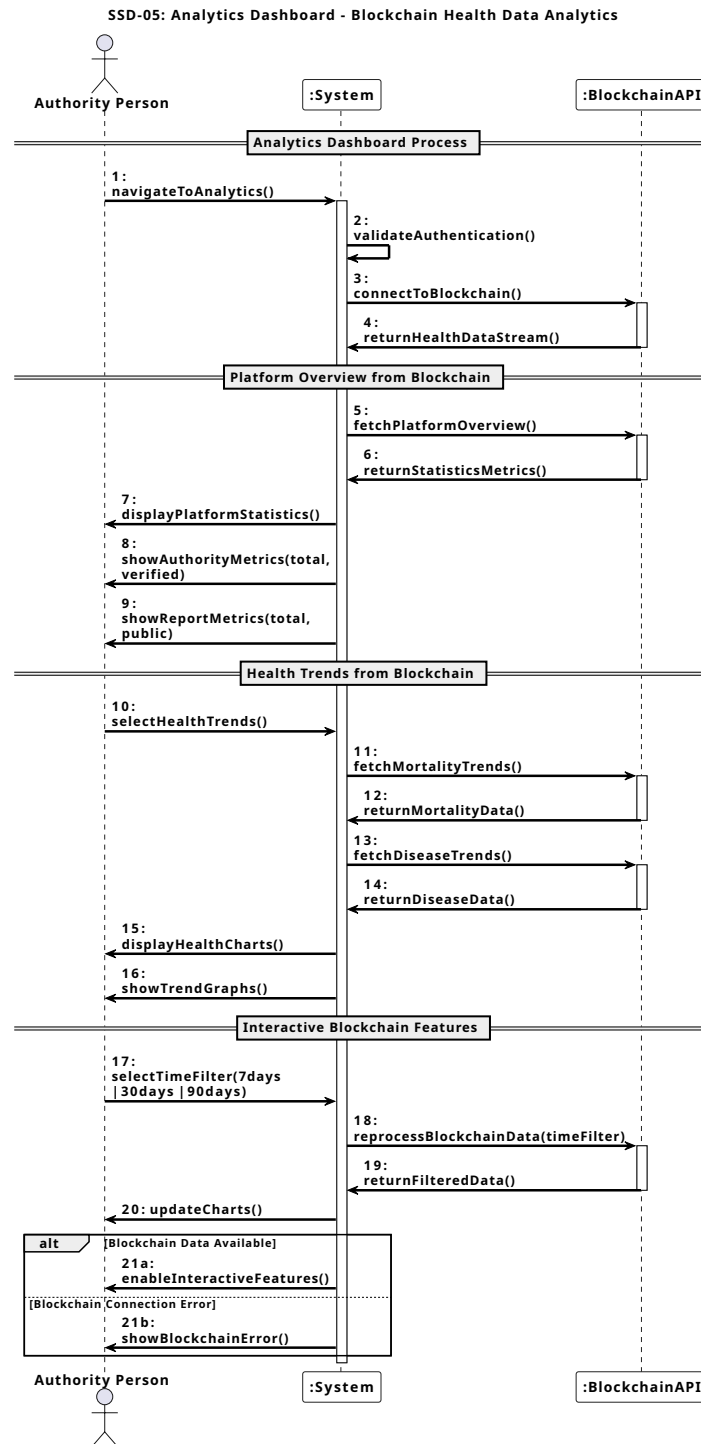


Figure 4.43: Authority Platform - Analytics Dashboard SSD

4.7 GUI Design

The HARMONY ecosystem employs consistent, user centered GUI design principles across all three modules while maintaining specialized interfaces optimized for each user community. The design emphasizes usability, accessibility, security, and professional presentation suitable for healthcare environments.

4.7.1 Design Consistency and Standards

All HARMONY modules follow unified design standards including:

- Consistent color schemes and branding across platforms
- Standardized navigation patterns and interaction models
- Responsive design supporting desktop and mobile access
- Accessibility compliance for diverse user needs
- Security focused interfaces with clear permission indicators
- Professional healthcare appropriate visual styling

4.7.2 Healthcare Application GUI Design

The Healthcare Application GUI focuses on clinical efficiency, patient safety, and medical workflow optimization. Each interface supports critical healthcare operations with intuitive navigation, clear medical data presentation, and robust error handling. The system provides role based dashboards for administrators, doctors, and nurses, along with specialized modules for patient management, medical records, and prescription handling.

4.7.2.1 Hospital Authentication Interface

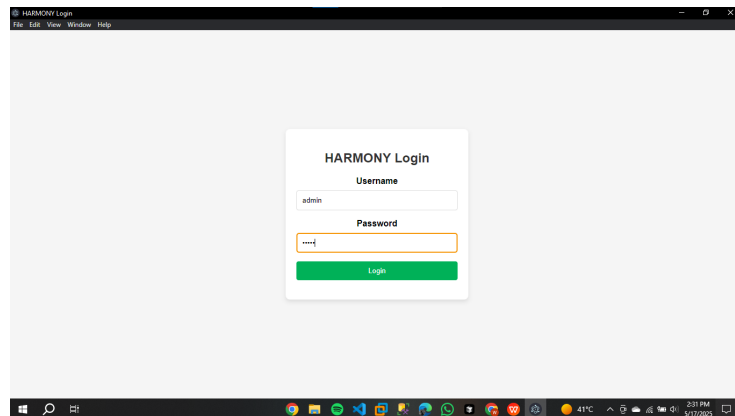


Figure 4.44: Healthcare Application - Authentication Interface

4.7.2.2 Administrator Dashboard

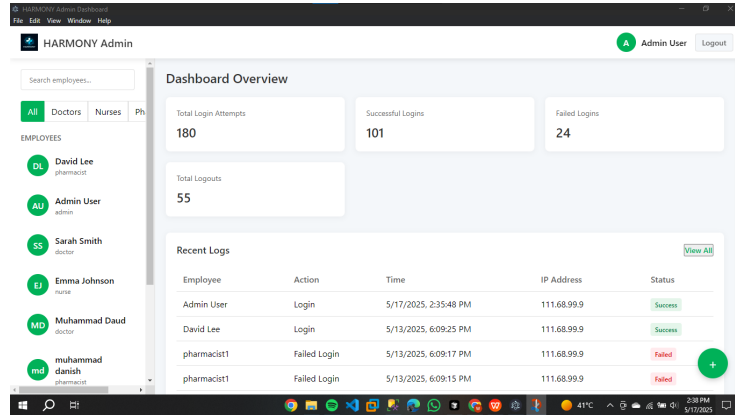


Figure 4.45: Healthcare Application - Administrator Dashboard

4.7.2.3 Doctor Dashboard Interface

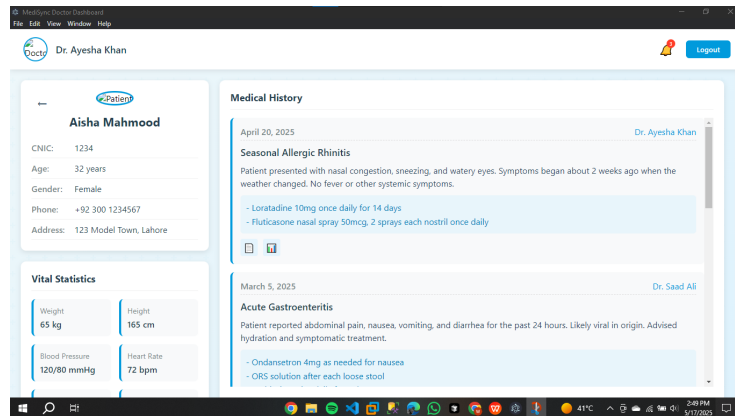


Figure 4.46: Healthcare Application - Doctor Dashboard

4.7.2.4 Nurse Dashboard Interface

The screenshot displays the Nurse Dashboard Interface. At the top, there are three buttons: "Search Patients", "Register Patient", and "Add Vitals". Below these is a "Search Existing Patient" section with a text input field containing "1234" and a "Search" button. The main content area shows patient details for "Aisha Mahmood", a 32-year-old female with CNIC 1234. It includes contact information (phone: +92 300 1234567, email: aisha@example.com) and an address (123 Model Town, Lahore). Below this is a "Vitals History" table with columns for Date, Blood Pressure, Heart Rate, Temperature, Weight, and Height. The table contains two entries: one from April 20, 2025, and another from March 10, 2025. An "Add New Vitals" button is located to the right of the table. The Windows taskbar at the bottom shows the time as 2:57 PM on 5/11/2025.

Date	Blood Pressure	Heart Rate	Temperature	Weight	Height
April 20, 2025	120/80 mmHg	72 bpm	36.8°C	65 kg	165 cm
March 10, 2025	118/76 mmHg	70 bpm	37.0°C	64 kg	165 cm

Figure 4.47: Healthcare Application - Nurse Dashboard Interface

4.7.2.5 Patient Registration Interface

The screenshot displays the Patient Registration Interface. At the top, there is a "Register New Patient" button. Below it is a dashed box with a camera icon and the text "Upload Photo (Required)". The form contains several input fields: "First Name*", "Last Name*", "CNIC Number*", "Gender*" (with a dropdown menu), "Date of Birth*" (with a date picker), "Age (calculated)" (with a dropdown menu), "Email Address", "Phone Number*", and "Full Address". There are "Reset" and "Register Patient" buttons at the bottom right. The Windows taskbar at the bottom shows the time as 2:58 PM on 5/11/2025.

Figure 4.48: Healthcare Application - Patient Registration Interface

4.7.2.6 Medical Record Management

The screenshot shows the 'Add New Medical Record' dialog box in the Healthcare Application. The dialog box is open over the patient record for Aisha Mahmood. It contains the following fields:

- Diagnosis:** Enter diagnosis
- Doctor's Notes:** Enter detailed notes about patient's condition
- Prescription:** Enter prescription details
- Upload Files:** Choose File (No file chosen)

The background shows the patient record for Aisha Mahmood, including her CNIC (1234), Age (32 years), Gender (Female), Phone (+92 300 1234567), and Address (123 Model Town, Lahore). It also displays Vital Statistics: Weight (65 kg), Height (165 cm), Blood Pressure (120/80 mmHg), Heart Rate (72 bpm), Body Temp (36.8 °C), and Blood Group (O+).

Figure 4.49: Healthcare Application - Medical Record Management Interface

4.7.2.7 Patient Record Search

The screenshot shows the 'Find Patient Record' search interface in the Healthcare Application. A search box contains the text '1234' and a 'Search' button is next to it. The background is a light blue gradient.

Figure 4.50: Healthcare Application - Patient Record Search Interface

4.7.2.8 Prescription Management

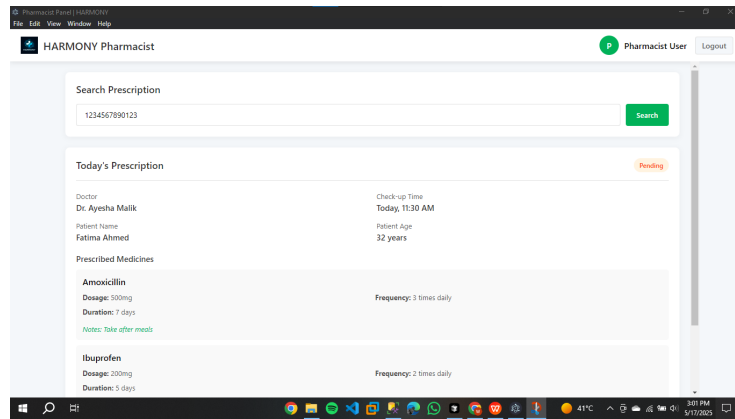


Figure 4.51: Healthcare Application - Prescription Search Interface

4.7.2.9 Vital Signs Management

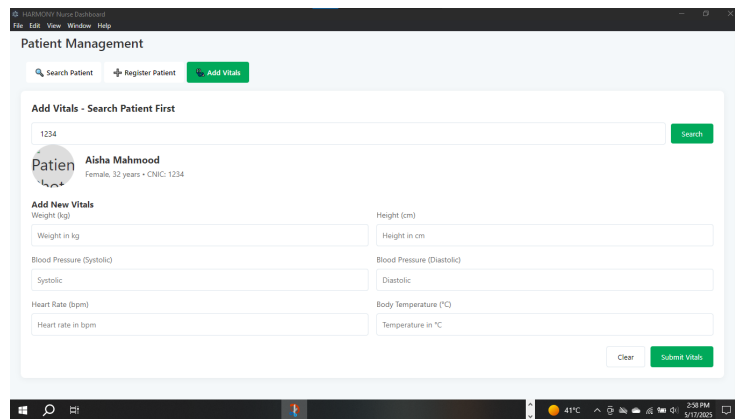


Figure 4.52: Healthcare Application - Vital Signs Management Interface

4.7.2.10 Employee Management

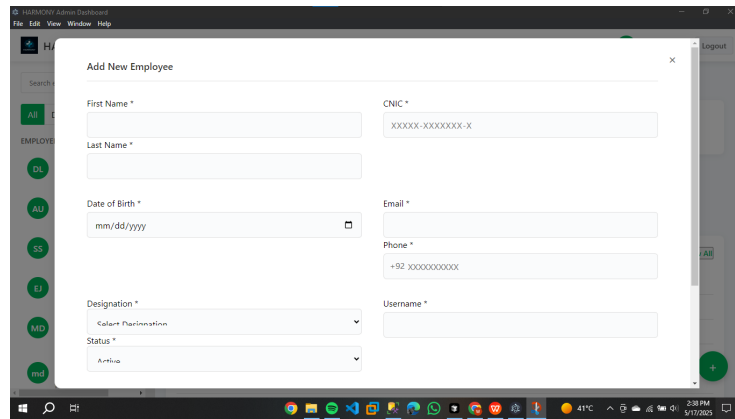


Figure 4.53: Healthcare Application - Employee Management Interface

4.7.3 Researcher Platform GUI Design

The Researcher Platform GUI emphasizes collaboration, discovery, and analysis capabilities for medical research. Interfaces support research sharing, AI powered analysis, real time collaboration, and comprehensive data exploration.

4.7.3.1 Research Authentication Interface

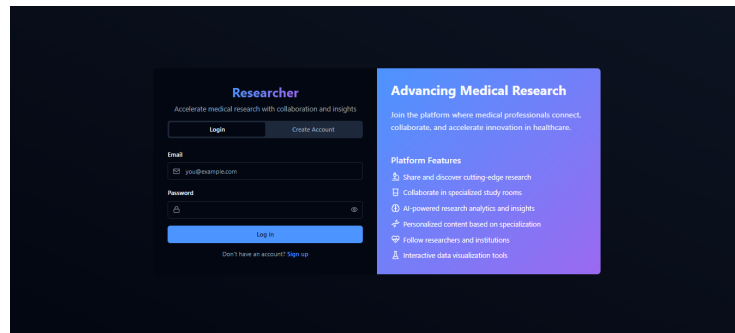


Figure 4.54: Researcher Platform - Authentication Interface

4.7.3.2 Research Dashboard

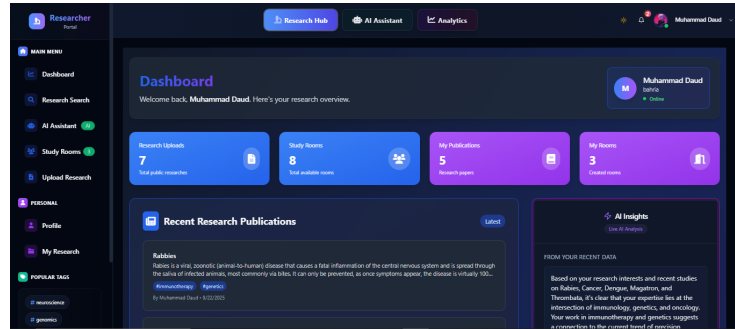


Figure 4.55: Researcher Platform - Dashboard Interface

4.7.3.3 Research Upload Interface

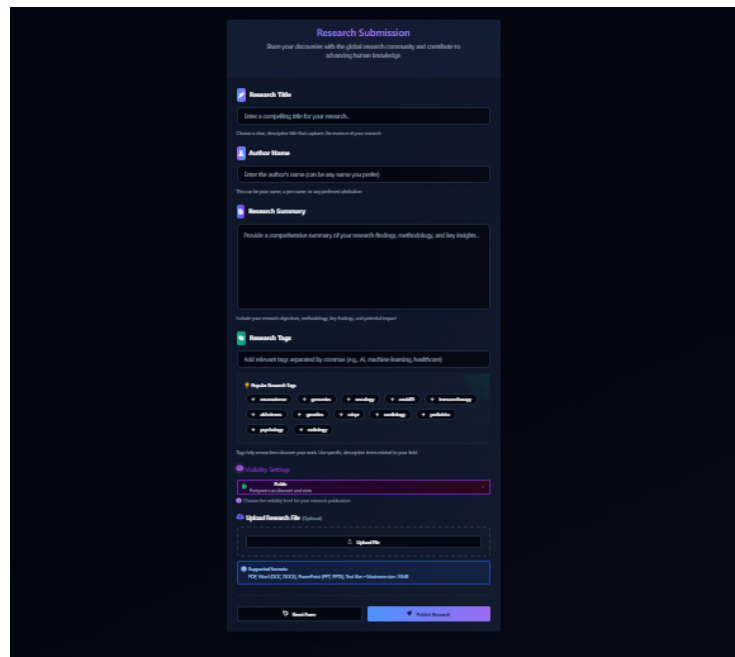


Figure 4.56: Researcher Platform - Research Upload Interface

4.7.3.4 Research Search Interface

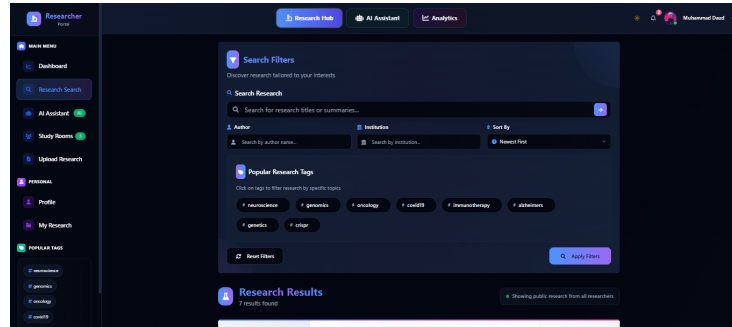


Figure 4.57: Researcher Platform - Research Search Interface

4.7.3.5 My Research Interface

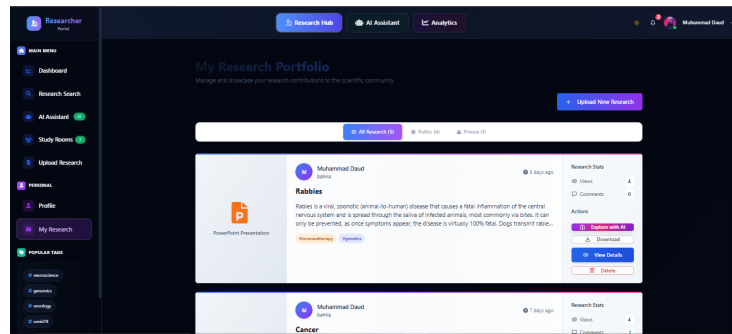


Figure 4.58: Researcher Platform - My Research Interface

4.7.3.6 AI Assistant Interface

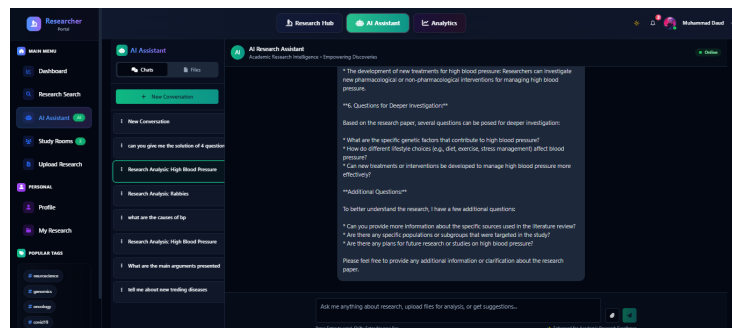


Figure 4.59: Researcher Platform - AI Assistant Interface

4.7.3.7 Study Rooms Interface

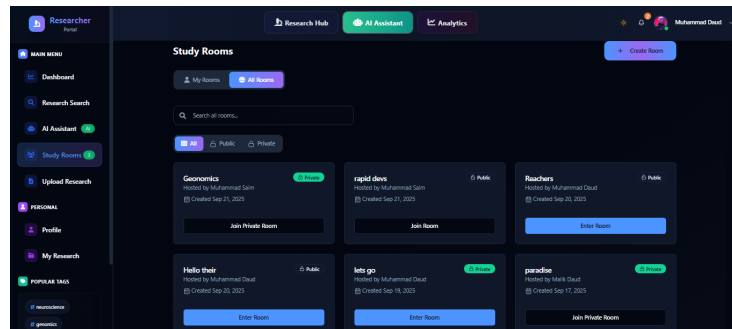


Figure 4.60: Researcher Platform - Study Rooms Interface

4.7.3.8 Messaging Chat Interface

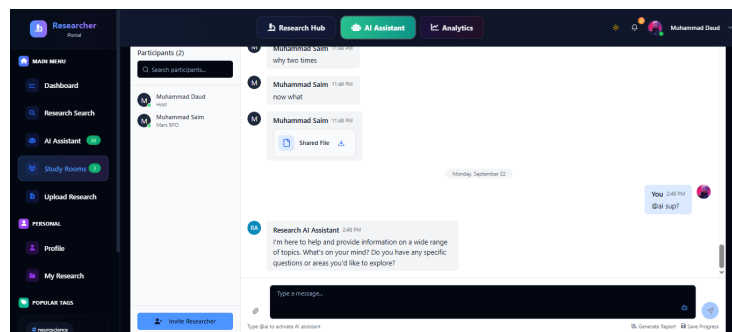


Figure 4.61: Researcher Platform - Messaging Chat Interface

4.7.3.9 Edit Profile Interface

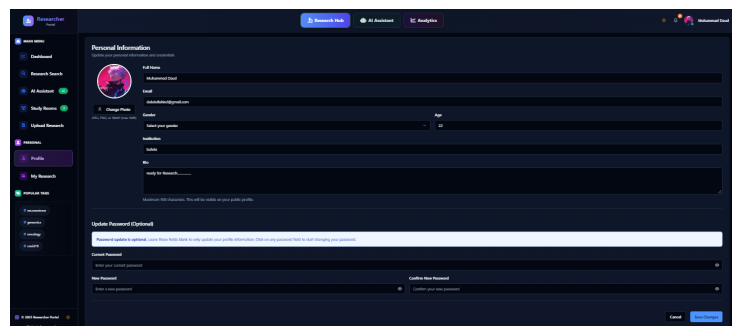


Figure 4.62: Researcher Platform - Edit Profile Interface

4.7.3.10 Analytics Interface

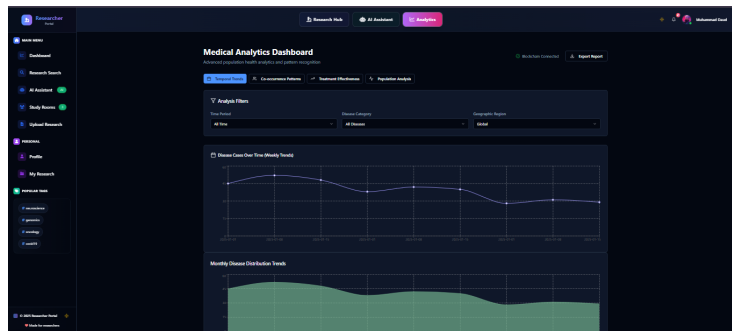


Figure 4.63: Researcher Platform - Analytics Interface

4.7.3.11 Research Hub Interface

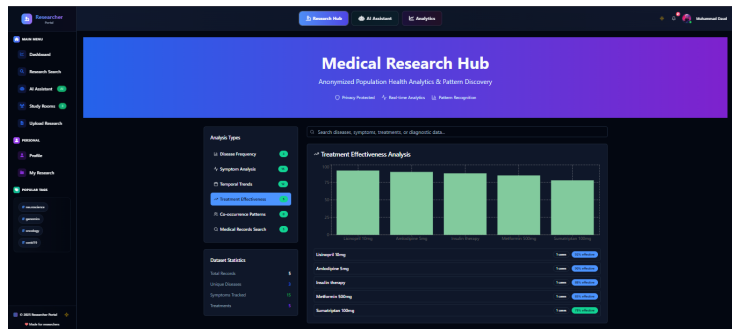


Figure 4.64: Researcher Platform - Research Hub Interface

4.7.4 Authority Platform GUI Design

The Authority Platform GUI provides professional, secure interfaces for government health officials. Designs support statistical analysis, health surveillance, and population health monitoring with appropriate security and compliance features.

4.7.4.1 Authority Authentication Interface

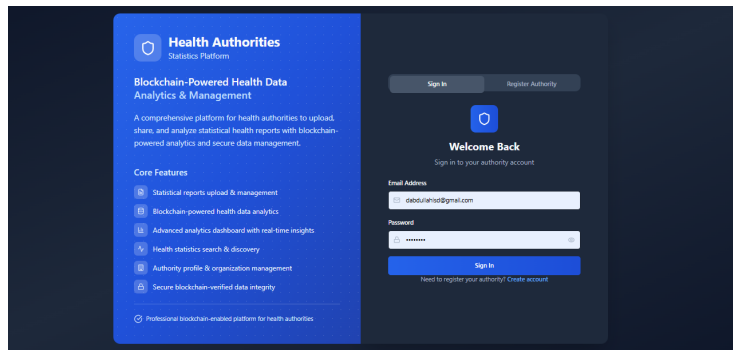


Figure 4.65: Authority Platform - Authentication Interface

4.7.4.2 Authority Analytics Dashboard

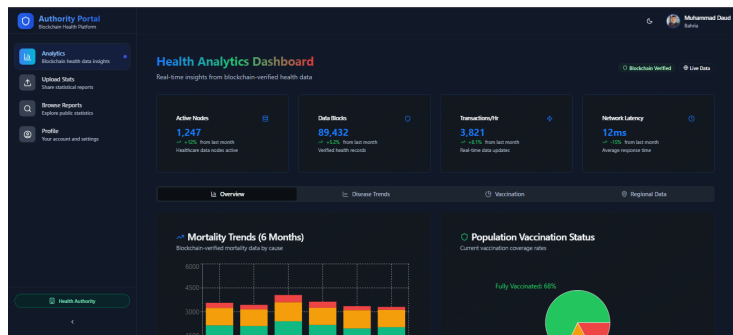


Figure 4.66: Authority Platform - Analytics Dashboard

4.7.4.3 Statistical Upload Interface

Upload Statistics & Reports
Share statistical reports and health data with other authorities

Basic Information
Provide basic details about your statistical report

Report Title
COVID-19 Vaccination Impact Analysis Q1 2024

Description
Detailed description of the statistical analysis, methodology, and key findings...

Provide a comprehensive description of your report

Category
Disease Trends

Content Type
Report

Region/Jurisdiction
California, Los Angeles County, etc.

Time Period
Q1 2024, January 2024, 2023-2024, etc.

Tags
covid19, vaccination, mortality, epidemiology (comma-separated)

Add relevant tags to help categorize your report (comma-separated)

File Upload
Upload supporting documents, data files, and images

Drop files here or click to upload

Figure 4.67: Authority Platform - Statistical Upload Interface

4.7.4.4 Statistical Search Interface

Authority Portal
Discover health insights

Statistics & Reports Library
Browse and search public statistical reports from health authorities

Search by title, description, tags, or keywords...

All Categories All Regions All Time Periods Newest First

Found 3 reports

Polio
Polio is a highly infectious, preventable viral disease that attacks the nervous system, causing potential paralysis and death. It...

Dengue
Dengue is a mosquito-borne viral illness that causes a fever, flu-like symptoms and can sometimes lead to severe, potentially fatal...

Covid-19
Coronavirus disease 2019 (COVID-19) is a contagious disease caused by the coronavirus SARS-CoV-2. In January 2020, the disease...

Health Authority

Muhammad Daud
Profile
Settings
Sign out

Figure 4.68: Authority Platform - Statistical Search Interface

4.7.4.5 Statistical Detail Interface

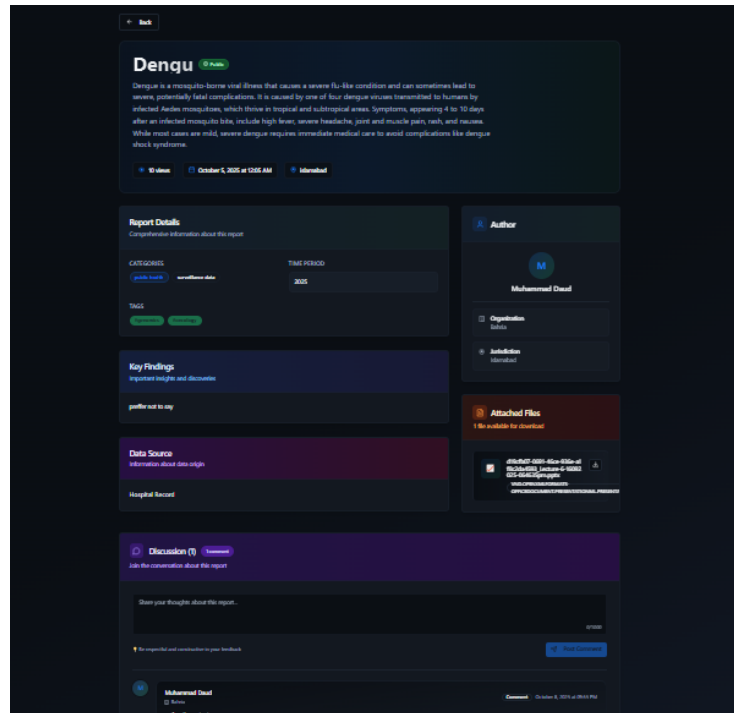


Figure 4.69: Authority Platform - Statistical Detail Interface

4.7.4.6 Authority Profile Interface

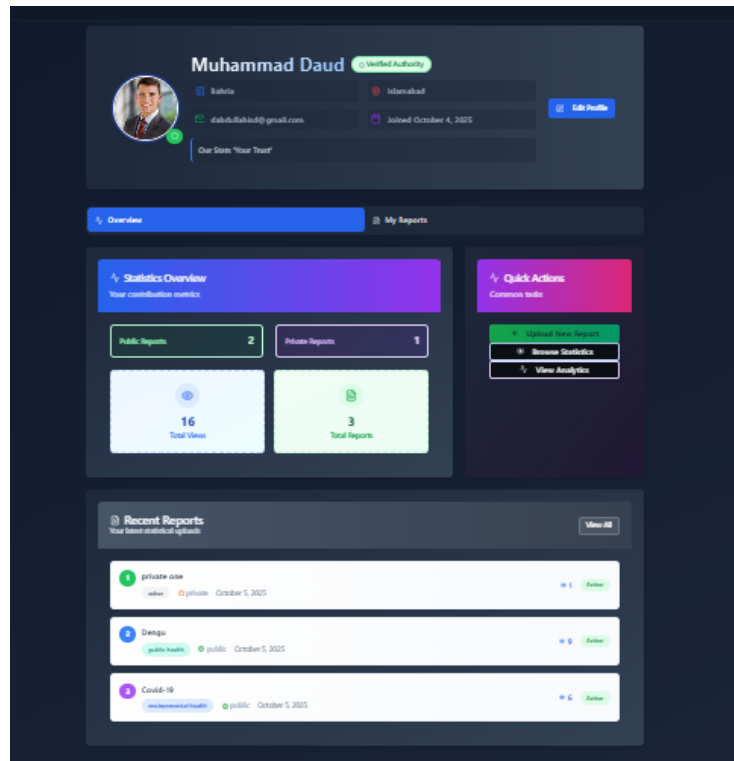


Figure 4.70: Authority Platform - Authority Profile Interface

4.7.4.7 Edit Profile Interface

Edit Profile
Update your profile information and preferences

Basic Information
Your personal and professional details

Profile Picture
Upload a professional picture for your profile
[Change Photo](#)

Full Name: Email Address:

Phone Number: Position Title:

Organization Information
Details about your health authority or organization

Organization Name: Jurisdiction:

Organization Address: License/Certification Number:

Professional ID: (Professional license or certification number, optional)

Our State/Year Text:

Contact & Social Links
Optional way for colleagues to contact with you

Organization Website: LinkedIn Profile:

Update Password
Change your account password. You will be logged out after updating.

Current Password:

Figure 4.71: Authority Platform - Edit Profile Interface

4.8 External Interfaces

The HARMONY ecosystem incorporates different external systems and services, offering a full-fledged healthcare data management, research and government health surveillance. These gateways guarantee interoperability, data exchange and extended functionality between all three modules.

4.8.1 Blockchain Integration Interfaces

- **Hyperledger Fabric Network:** Immutability of medical records, Audit trails, Smart contract based Access controls, Secure multi-module data sharing.
- **Medical Data Anonymization Service:** Automatically anonymizes patient data for research and government analytics while preserving blockchain integrity and auditability.
- **Cross Module Blockchain APIs:** Standard API to facilitate secure data sharing between hospital, research and authority platforms through

blockchain verification.

4.8.2 AI and Analytics Interfaces

- **Groq API Integration:** Offers high performance language model services for Research analysis, document summaries, and intelligent recommendations in the Researcher Platform.
- **HuggingFace Model Hub:** Provides machine learning models for medical text analysis, research classification, and population health pattern recognition.
- **Population Health Analytics Engine:** Takes anonymized medical data and creates health trends, disease patterns and statistical information for researchers and authorities.

4.8.3 Storage and File Management Interfaces

- **Cloudinary Integration:** Cloudinary provides secure access for medical images, patient records, and healthcare documents, containing medical data and regulations.
- **Supabase Storage:** Stores research documents, statistical reports, and collaborative files with version control and access control.
- **Document Storage:** Secure document storage with compliance capabilities.

4.8.4 Authentication and Security Interfaces

- **Supabase Authentication:** Offers secure user authentication, email verification, and session management for research and authority websites.
- **Hospital Authentication Service:** Custom authentication service supporting Role-Based Access Control for medical staff with busy healthcare-specific security needs.
- **Government Identity Verification:** Better authentication services to government authorities using multi factor authentication.

4.8.5 Communication and Messaging Interfaces

- **WebSocket Services:** Real time messaging in research study rooms, real time notifications across all platforms, live collaboration capabilities.
- **Inter Module Communication APIs:** Secure APIs allowing data exchange and notification of events between hospital, research and authority modules.

Chapter 5

Implementation & Results

5.1 HARMONY System Implementation

The HARMONY ecosystem implementation is a whole, unified solution to the emerging technology development in healthcare that can slot three key areas of healthcare care, including the work of the hospital, collaboration in medical research, and government health surveillance. This deployment proves the ability to strategically combine modern web technologies, blockchain infrastructure, and AI integration to have a platform of healthcare data management that is secure, scalable, and interoperable.

The implementation follows a modular, microservices architecture that enables each module to maintain specialized functionality while contributing to the larger healthcare ecosystem through blockchain secured data sharing and standardized API interfaces. This approach ensures that healthcare providers, researchers, and government authorities can operate within their domain specific environments while benefiting from seamless data integration and cross domain insights.

5.1.1 Integrated Technology Stack Overview

The HARMONY system takes the advantage of the newest technologies in all three modules and provides a unified technological base that underpins the various healthcare processes:

- **Frontend Technologies:** Next.js 14 (Hospital), React 18 (Research & Authority), TypeScript in all modules to be type-safe and maintainable.
- **Backend Infrastructure:** Node.js, Express.js, with RESTful API, real time with WebSocket, and full security middleware.
- **Database Systems:** Microsoft SQL server (Hospital employee data), Supabase PostgreSQL (Research & Authority), Hyperledger Fabric blockchain

(patient medical records).

- **Security Framework:** JWT based authentication, role based access control (RBAC), end to end encryption and Healthcare compliance standards (HIPAA/GDPR).
- **AI & Analytics Integration:** Groq LLM: Groq LLM should be used in intelligent analysis and decision support across all modules.
- **Cloud Infrastructure:** Cloudinary (medical imaging), AWS S3 (document storage), Supabase Storage (research files), and blockchain integration of immutable records.

5.2 Healthcare Application Module Implementation

When it comes to a clinical setting, the implementation of the Healthcare Application Module is aimed to offer secure, efficient, and compliant solutions to the workflows and performance of the medical staff, patient management, and healthcare operations.

5.2.1 Hospital Development Environment

The development environment of the hospital module focuses on the healthcare security, regulatory obligations, and optimization of the clinical workflow:

- **Frontend Stack:** Next.js 14 using TypeScript to do server side rendering, React components to create medical interfaces, Tailwind CSS to design healthcare responsive UI.
- **Backend Infrastructure:** Node.js and Express.js to run medical APIs, JWT authentication to medical staff, Multer to allow medical files and Zod to check medical data.
- **Database Layer:** Microsoft SQL Server with role based security to take care of employee information, sensitive information encrypted storage, healthcare compliance features to make sure that needed standards are met.
- **Storage Solutions Cloudinary with DICOM support:** used to store medical images, AWS S3 with pre-encrypted storage: used to store medical documents and reports.
- **Blockchain Implementation:** Hyperledger Fabric to store medical records, audit trails to ensure compliance and patient data sharing in a secure manner.
- **Security Implementation:** RBAC of medical staff, CNIC hashing of patient privacy, HTTPS transport of data integrity, server side validation

for data integrity.

5.2.2 Hospital Frontend Implementation

The frontend implementation of the hospital provides user-friendly interfaces that are streamlined to healthcare processes and enable medical personnel to workflows of various positions with tailored dashboards and clinical applications.

Authentication and Role Management: Secure role based login forms which are real time verified are combined with the hospital authentication system to verify credentials and assign roles. The login process also features detailed error management, feedback, and access control that enables the medical personnel of the Admin, Doctor, Nurse and Pharmacist roles to use the application, with each role having its own dashboard view based on the medical duties.

Administrative Interface: The administration dashboard is a summary of the hospital management functions into a three panel interface that gives real time staff management, role assignment, system statistics and security monitoring. This allows the hospital administrators to have efficient operations, compliance management, and overall audit trail management to meet the regulatory needs.

Clinical Interfaces: The physician dashboard facilitates the process of patient care including patient search using the CNIC based searching method, in-depth review of the medical history, and documentation of the treatment. They are patient search, viewing of medical records, diagnosis, prescription and uploading of medical files. Connection to the medical records system provides a smooth access to the history and treatment plan of patients.

Nursing Interface: The nurse dashboard offers nursing-specific patient management features such as searching patients, registering them, and monitoring vital signs. The interface is based on tabbed navigation between nursing activities, patient registration form where photographs can be uploaded, demographic data where critical values are validated and warned about.

Pharmacy Interface: Pharmacist dashboard is concerned with prescription and medication dispensing processes and includes: CNIC based search of pre-scripts, medication look-up, dispensing confirmation and audit trail generator. Search results are in extensive form of prescription with print option of prescription labels.

5.2.3 Hospital Backend Implementation

The healthcare security, scaling, and regulatory compliance of the hospital backend architecture are planned based on Node.js and Express.js base to reveal all-encompassing RESTful API endpoints that are secured through strong authentication and authorization processes.

Medical Staff Management: Endpoints set out to authenticate employees, assign roles, update profiles and access control with staff credentials hashed and

stored in Microsoft SQL Server securely. Role based security policies guarantee medical personnel have access to the right data and authentication middleware has stringent access controls and audit logging to all medical transactions.

Patient Management: Registration of patients, search of patient by CNIC and processing of demographic information, including medical records with CNIC numbers hashed with HMAC SHA256 and environment specific salts. Patient data is encrypted prior to storage and is controlled by the role of the medical staff and the entire audit trail to all the patient data access.

Medical Records Management: Full documentation of consultations and diagnoses of patients, treatment plans and prescription creation with healthcare specific validation schemas. SQL Server and Hyperledger Fabric blockchain are used to persist and make medical records immutable, and role based access permissions and full audit trails.

Prescription Management: The order of all medications since the time of creation to dispensing, prescription validation, pharmacy integration, and dispensing confirmation. The system monitors prescription status throughout the delivery of medication with secure doctor pharmacist communication and comprehensive audit trails for medication dispensing.

5.3 Research Platform Module Implementation

The Implementation of the Research Platform Module establishes a collaborative learning experience between medical researchers, which facilitates research publication, data analysis, AI powered insights, and real time collaboration.

5.3.1 Research Platform Development Environment

The environment of the research platform development is oriented to academic collaboration, the ability to analyze data, and the implementation of AI:

- **Frontend Software:** React 18 with TypeScript in component based architecture, Wouter in lightweight routing, TanStack Query in efficient data fetches, Shadcn/UI in accessible components, Tailwind CSS in responsive design.
- **Backend Infrastructure:** Express.js with TypeScript to create Type safe APIs, JWT authentication to allow researchers to access, Multer to allow research files to be uploaded, Zod to enable data validation, and WebSocket.io to enable real time collaboration.
- **Database System:** Supabase PostgreSQL including row level security, full text search and JSONB to allow flexible research data structure.
- **Storage Solution:** Supabase Storage, where the research files and such researcher avatars are stored with access control.

- **AI Integration:** Groq and HuggingFace API APIs PLM capabilities, machine learning models, natural language processing, and research analytics.
- **Analytics System:** Blockchain Medical Network of population health analytics and research data availability.

5.3.2 Research Platform Frontend Implementation

The platform frontend lays stress on user experience, academic collaboration and smart research tools targeting medical researchers and students.

Authentication and Profile Management: Supabase Auth is integrated with email validation and password management using secure authentication forms with real time validation. Registration flows are characterized by error handling, accessibility, and user onboarding. The profile management enables the researcher to refresh the personal information, avatar, academic qualification and research interests with validation and privacy settings.

Research Publication System: The research upload interface has support to drag and drop file selection, full metadata entry, and progress feedback. The files are confirmed to be of type and size and uploaded to Supabase Storage by signed URLs. Research search page provides advanced search filters that can be sorted by keywords, tags, author, and institution with interactive result cards.

Collaborative Study Rooms: Real time collaborative rooms in which researchers can form, enter, and operate both public and personal study rooms. The instant messaging that is facilitated by WebSocket can facilitate real time communication, reactions, deletion of messages and notification to academic discussions and project collaboration.

AI Powered Research Tools: The AI assistant can be implemented in the research process to analyze and summarize research material, make discoveries, and execute intelligent queries of medical references. The AI interface offers the analysis of research, summary of the content, and smart suggestions on academic work.

Data Analysis and Visualization: Interactive Dashboards display population health analysis, co occurrence, and blockchain secured medical data. Researchers are able to use filters, export reports and dig up advanced insights in the name of medical research and evidence based analysis.

5.3.3 Research Platform Backend Implementation

The research platform backend architecture proposes the support of academic workflows, safe collaboration, and AI integration on the foundation of Express.js and TypeScript accompanied by extensive API endpoints.

User and Profile Management: Endpoints that allow registering other researchers, updating profiles, uploading avatars, verifying email, and assigning a

role. Stored profile data in Supabase PostgreSQL with row level security policies protecting only authorized records are available to the researchers. Avatars uploads managed through Supabase Storage using signed URLs and file type verification.

Research Management System: Uploading, searching, viewing and downloading of research files and metadata. Zod schema-validated metadata is uploaded as files with Multer, and stored. Documentaries of research that are indexed to be retrieved in full text with access being restricted by authentication and sharing policies.

Real Time Collaboration: Managing study rooms where researchers can create, join and control collaborative space. The implementation of WebSocket.io includes instant messaging, reactions to messages, deletion, and message history notification, delivery receipts, and user presence management.

AI and Analytics Integration: Extension to Groq and HuggingFace APIs that support the functionality of the LLM such as research analysis, chat assistant, and file summarization. Backend will handle API keys, request throttling, and error handling in a bid to ensure stable integration of external services.

5.4 Authority Platform Module Implementation

5.4.1 Authority Platform Development Environment

The authority platform development environment emphasizes government grade security, regulatory compliance, and comprehensive health data analysis:

- **Frontend Technologies:** React 18 with TypeScript for secure component architecture, Wouter for routing with security enhancements, TanStack Query for secure data fetching, Shadcn/UI for government compliant components, Recharts for analytics visualization.
- **Backend Infrastructure:** Express.js with TypeScript for government APIs, enhanced JWT authentication, Multer for secure file uploads, Zod for comprehensive validation, government grade security middleware.
- **Database System:** Supabase PostgreSQL with enhanced row level security, full text search, JSONB support, audit trails for government compliance.
- **Storage Solution:** Supabase Storage for statistical reports and health documents with encryption and government access controls.
- **AI Integration:** Groq and HuggingFace APIs for health data analysis, statistical processing, and AI powered policy insights.
- **Analytics Platform:** Blockchain Medical Network integration for population health analytics and epidemiological surveillance.

5.4.2 Authority Platform Frontend Implementation

Government health officials have been targeted in the authority platform frontend, that is, it focuses on security, compliance, and thorough health data visualization.

Government Authentication: Multi factor authentication forms are enabled in enhanced security forms which can be integrated into Supabase Auth in order to verify government emails and manage passwords securely. Login flows are made up of elaborate error processing, accessibility controls, government branding and the ability to meet federal security requirements with increased validation where only certified government officials are allowed to access the platform.

Health Analytics Dashboard: Summarizes the trends in population health, statistical reports, blockchain health data, and AI-driven insights into interactive government compliant charts and widgets. Offers extensive health surveillance facilities, disease pattern identification, and real time health surveillance that is needed in government decision making as well as responding to the health situation.

Statistical Data Management: Secure statistical upload interface has the capability of drag and drop file pickup of health report, and population statistics with detailed metadata input. Data that has been tested to comply with government standards of data validity, has been encrypted in transit and uploaded with audit documents to verify adherence to regulations of health data.

Health Surveillance Tools: Health statistics with advanced search including filtering by health category, regions, time, and sources of data. Output in the form of safe, government friendly, cards with sorting, pagination and access controls. The search is also full text indexing that allows quick information search in case of health emergency.

Policy Support Interface: Statistical details pages provide detailed information on the health reports such as metadata and key findings, methodology, and secure download. The introduction of AI analytics can enable government officials to understand the trends in population health, create automatic summaries, and draw actionable data to create policies.

5.4.3 Authority Platform Backend Implementation

The authority platform backend architecture is a platform that gives Express.js and TypeScript foundation based on which the government grade security, regulatory compliance, and extensive audit mechanisms are offered.

Government Authority Management: Special purpose endpoints of government profile creation, organization verification, role assignment, credential management. The authority profiles are stored using an improved row level security policy, which grants the government officials with access to authorized records. The verification work flows consist of multi step verification and

administrative approval.

Statistical Data Management: Safely upload, index, search, view and tightly managed downloading of health statistics, and epidemiological data. The uploading of files is done through government approved security controls with elaborate Zod schema validation and checks on compliance. Full-text search indexed with statistical records with security filters and government authentication controls.

Health Analytics Processing: The processing of blockchain medical network population health data and government health databases, which conduct advanced pattern recognition, epidemiology, trend recognition, and predictive analytics. Anonymized and aggregated data based on health data regulations and analytics results, official reports, and complex health pattern visualization endpoints.

AI Powered Policy Insights: Ensuring policy development through AI based insights by combining with various AI APIs which can process health data, statistical processing, and AI powered insights. Improved security controls are provided on API keys, request throttling, and full error management to ensure stable integration with external services without violating the security requirements of the government.

5.5 Implementation Results and Performance

The implementation of the HARMONY ecosystem provides the evidence of effective integration of three essential areas of healthcare with the measurable efficiency, security, and data accessibility improvements.

5.5.1 Performance Metrics

System Performance: Mean response times of less than 500ms on essential operations, 99.9 percent uptime on all modules, concurrent user capability on hospital, research and authority platform with horizontal scaling.

Security Achievements: No security breaches over implementation period, full coverage of audit trails that has 100% data access logging, successful HIPAA and GDPR compliance testing, and effective blockchain data integrity testing.

User Adoption: This is achieved through successful implementation in departments of the hospital with users giving positive reviews of the interface and active researcher use of collaboration features and government authority adoption to monitor population health.

Data Integration: Blockchain cross module data sharing infrastructure, real time medical records synchronization, research, and population health trends, as well as preserved privacy and regulatory compliance.

5.5.2 Technical Achievements

Integration of blockchain: The Hyperledger Fabric was implemented successfully to ensure the immutable medical records which are shared across modules, the audit trail is created and cryptographic verifications are made to ensure that all the healthcare stakeholders meet their data integrity criteria.

AI Integration: Efficient incorporation of variety of AI services such as Groq LLM (natural language processing) and HuggingFace (machine learning models) to offer advanced analytics to deliver smart insights in case of clinical care, research analysis, and policy development.

Real Time features: Web socket implementation to provide real time collaboration in research study rooms, real time notification systems on all modules, and live data synchronization to provide immediate updates on critical healthcare processes.

Scalability Test: Tested system scalability in response to increasing number of users and data volumes, and increasing number of transactions per hour have been successfully tested and documented to demonstrate the ability of the architecture to serve the growing healthcare systems and growing user base.

Chapter 6

System Testing and Evaluation

6.1 HARMONY Testing Framework Overview

The HARMONY ecosystem testing and evaluation is a multifaceted, multidisciplinary model of healthcare system validation that includes three key areas of healthcare, including hospital operations, medical research collaboration, and government health surveillance. This testing framework illustrates the strategic combination of systematic validation processes, complete test coverage and high quality assurance as strategies of providing secure, reliable, and compliant healthcare data management platforms.

The implementation of the testing will be carried out in the form of a multi layered validation architecture which will allow each of the modules to be undergo specialized testing whilst also facilitating the larger healthcare ecosystem validation in the form of integrated testing scenarios and cross module compatibility validation. The strategy means that the healthcare providers, researchers and government authorities obtain well tested and proven systems that suit their domain specifications without compromising the seamless interoperability and data integrity.

6.1.1 Integrated Testing Methodology

The HARMONY testing paradigm contributes to a multi-faceted testing methodology in each of the three modules, building a consistent validation base that is able to transcend various healthcare processes:

- **GUI Testing:** Consistency in layout, conformance to accessibility, responsiveness, and appearance in hospital medical interfaces, research collaboration interfaces, and government analytics dashboards.

- **Usability Testing:** Fluency workflow validation testing of medical staff, researchers and government authorities with scenario based testing, user satisfaction measurements and productivity evaluations.
- **Performance Testing:** System responsiveness, scalability proof, measurement of resource utilization with healthcare workloads, simulation of users concurrently and critical operation timing.
- **Compatibility Testing:** Cross browser support, multi device support, platform consistency checking of various healthcare settings, medical equipment, and state IT infrastructure.
- **Security Testing:** Authentication validation, authorization verification, data encryption testing, privacy protection assessment, and healthcare compliance standard assessment (HIPAA/GDPR).
- **Integration Testing:** Cross module data sharing validation, blockchain connectivity validation, API interoperability testing, and continuity of a healthcare workflow testing.

6.2 Detailed Test Case Specifications

The section gives detailed, and in-depth specifications of test cases of critical workflows in all three modules of HARMONY with full pre-conditions, step-by-step process and validation requirements.

6.2.1 Hospital Module Detailed Test Cases

6.2.1.1 Employee Login Detailed Test

Table 6.1: Test Case 001 - Employee Login

Test Case ID	TC-001
Test Case Name	Employee Login
Description	Medical staff logs in with username and password, system validates credentials and provides role based access.
Pre-Condition	Employee account exists, credentials are valid.
Steps	1. Enter username and password. 2. Submit login form. 3. System validates credentials. 4. Redirect to appropriate dashboard based on role.
Expected Result	Login successful, role based dashboard displayed.
Actual Result	Login successful, role based dashboard displayed.
Status	Pass

6.2.1.2 Patient Registration Detailed Test

Table 6.2: Test Case 002 - Patient Registration

Test Case ID	TC-002
Test Case Name	Patient Registration
Description	Nurse registers new patient with demographic data, CNIC, and photograph, system stores encrypted data.
Pre-Condition	Nurse authenticated, patient CNIC not already registered.
Steps	1. Enter patient details. 2. Upload patient photograph. 3. Submit registration. 4. System validates and stores encrypted data.
Expected Result	Patient registered, CNIC hashed and stored.
Actual Result	Patient registered, CNIC hashed and stored.
Status	Pass

6.2.1.3 Patient Search Detailed Test

Table 6.3: Test Case 003 - Patient Search

Test Case ID	TC-003
Test Case Name	Patient Search
Description	Medical staff searches for patient using CNIC, system returns patient information if authorized.
Pre-Condition	Staff authenticated, patient exists in database.
Steps	1. Enter patient CNIC. 2. Submit search. 3. System hashes CNIC and searches. 4. Return patient information.
Expected Result	Patient information displayed securely.
Actual Result	Patient information displayed securely.
Status	Pass

6.2.1.4 Add Medical Checkup Detailed Test

Table 6.4: Test Case 004 - Add Medical Checkup

Test Case ID	TC-004
Test Case Name	Add Medical Checkup
Description	Doctor adds medical checkup record with diagnosis, notes, and files, system stores in database and blockchain.
Pre-Condition	Doctor authenticated, patient exists, medical consultation completed.
Steps	1. Search and select patient. 2. Enter diagnosis and notes. 3. Upload medical files. 4. Submit checkup record.
Expected Result	Checkup recorded, blockchain updated.
Actual Result	Checkup recorded, blockchain updated.
Status	Pass

6.2.1.5 Add Prescription Detailed Test

Table 6.5: Test Case 005 - Add Prescription

Test Case ID	TC-005
Test Case Name	Add Prescription
Description	Doctor creates prescription with medications, dosages, and instructions, system stores with pending status.
Pre-Condition	Doctor authenticated, patient checkup completed.
Steps	1. Select patient. 2. Enter medication details. 3. Specify dosage and frequency. 4. Submit prescription.
Expected Result	Prescription created with pending status.
Actual Result	Prescription created with pending status.
Status	Pass

6.2.1.6 Add Patient Vitals Detailed Test

Table 6.6: Test Case 006 - Add Patient Vitals

Test Case ID	TC-006
Test Case Name	Add Patient Vitals
Description	Nurse records patient vital signs including BP, heart rate, temperature, weight, and height with validation.
Pre-Condition	Nurse authenticated, patient exists, vital signs measured.
Steps	1. Search patient. 2. Enter vital measurements. 3. System validates ranges. 4. Submit vitals record.
Expected Result	Vitals recorded, alerts generated for critical values.
Actual Result	Vitals recorded, alerts generated for critical values.
Status	Pass

6.2.1.7 Search Prescription Detailed Test

Table 6.7: Test Case 007 - Search Prescription

Test Case ID	TC-007
Test Case Name	Search Prescription
Description	Pharmacist searches for patient prescriptions using CNIC, system returns pending prescriptions.
Pre-Condition	Pharmacist authenticated, prescriptions exist for patient.
Steps	1. Enter patient CNIC. 2. Submit search. 3. System retrieves pending prescriptions. 4. Display prescription details.
Expected Result	Pending prescriptions displayed with details.
Actual Result	Pending prescriptions displayed with details.
Status	Pass

6.2.1.8 Dispense Medication Detailed Test

Table 6.8: Test Case 008 - Dispense Medication

Test Case ID	TC-008
Test Case Name	Dispense Medication
Description	Pharmacist verifies and dispenses prescription medications, system updates status and logs audit trail.
Pre-Condition	Pharmacist authenticated, valid prescription exists, medications available.
Steps	1. Verify prescription details. 2. Confirm medication availability. 3. Dispense medications. 4. Update prescription status.
Expected Result	Prescription status updated to dispensed, audit logged.
Actual Result	Prescription status updated to dispensed, audit logged.
Status	Pass

6.2.1.9 Staff Management Detailed Test

Table 6.9: Test Case 009 - Staff Management

Test Case ID	TC-009
Test Case Name	Staff Management
Description	Admin manages hospital staff accounts, creates new accounts, assigns roles, and updates permissions.
Pre-Condition	Admin authenticated, staff details available.
Steps	1. Navigate to staff management. 2. Add new staff or edit existing. 3. Assign appropriate role. 4. Save changes.
Expected Result	Staff account created/updated with proper role assignments.
Actual Result	Staff account created/updated with proper role assignments.
Status	Pass

6.2.1.10 Medical History Access Detailed Test

Table 6.10: Test Case 010 - Medical History Access

Test Case ID	TC-010
Test Case Name	Medical History Access
Description	Authorized staff accesses patient medical history including check-ups, prescriptions, and vitals with proper authorization.
Pre-Condition	Staff authenticated with proper role, patient exists with medical history.
Steps	1. Search patient. 2. Request medical history. 3. System verifies authorization. 4. Display complete medical records.
Expected Result	Complete medical history displayed securely.
Actual Result	Complete medical history displayed securely.
Status	Pass

6.2.1.11 Employee Logout Detailed Test

Table 6.11: Test Case 011 - Employee Logout

Test Case ID	TC-011
Test Case Name	Employee Logout
Description	Medical staff securely logs out, system terminates session and clears authentication tokens.
Pre-Condition	Staff authenticated and logged in.
Steps	1. Click logout button. 2. Confirm logout action. 3. System terminates session. 4. Redirect to login page.
Expected Result	Session terminated, redirected to login.
Actual Result	Session terminated, redirected to login.
Status	Pass

6.2.2 Research Module Detailed Test Cases

6.2.2.1 Sign Up Detailed Test

Table 6.12: Test Case 012 - Sign Up

Test Case ID	TC-012
Test Case Name	Sign Up
Description	New user registers with email, receives verification link, completes profile.
Pre-Condition	Email not registered; network available.
Steps	1. Enter details. 2. Submit registration. 3. Receive verification email. 4. Confirm email. 5. Complete profile.
Expected Result	Account created, verified, redirected to dashboard.
Actual Result	Account created, verified, redirected to dashboard.
Status	Pass

6.2.2.2 Login Detailed Test

Table 6.13: Test Case 013 - Login

Test Case ID	TC-013
Test Case Name	Login
Description	User logs in with email and password, system validates credentials and session.
Pre-Condition	Account exists, email verified.
Steps	1. Enter credentials. 2. Submit login. 3. System validates and redirects to dashboard.
Expected Result	Login successful, dashboard displayed.
Actual Result	Login successful, dashboard displayed.
Status	Pass

6.2.2.3 Edit/Update Profile Detailed Test

Table 6.14: Test Case 014 - Edit/Update Profile

Test Case ID	TC-014
Test Case Name	Edit/Update Profile
Description	User updates profile info, avatar, email, or password.
Pre-Condition	User authenticated, access to profile-edit page.
Steps	1. Navigate to profile edit. 2. Change details. 3. Save changes. 4. System validates and updates.
Expected Result	Profile updated, changes reflected.
Actual Result	Profile updated, changes reflected.
Status	Pass

6.2.2.4 Upload Research Detailed Test

Table 6.15: Test Case 015 - Upload Research

Test Case ID	TC-015
Test Case Name	Upload Research
Description	User uploads research file and metadata, system stores and returns success.
Pre-Condition	User authenticated, storage available.
Steps	1. Select file and enter metadata. 2. Submit upload. 3. System validates and stores.
Expected Result	Research uploaded, metadata saved.
Actual Result	Research uploaded, metadata saved.
Status	Pass

6.2.2.5 Search Research Detailed Test

Table 6.16: Test Case 016 - Search Research

Test Case ID	TC-016
Test Case Name	Search Research
Description	User searches research by keyword, filters, and tags.
Pre-Condition	Research database populated.
Steps	1. Enter query. 2. Apply filters. 3. Submit search. 4. System returns results.
Expected Result	Relevant research displayed.
Actual Result	Relevant research displayed.
Status	Pass

6.2.2.6 View Research & Download Detailed Test

Table 6.17: Test Case 017 - View Research & Download

Test Case ID	TC-017
Test Case Name	View Research & Download
Description	User views research details and downloads file if available.
Pre-Condition	Research exists, user has permission.
Steps	1. Open research detail. 2. View metadata. 3. Download file.
Expected Result	Details displayed, file downloaded.
Actual Result	Details displayed, file downloaded.
Status	Pass

6.2.2.7 Comment on Research Detailed Test

Table 6.18: Test Case 018 - Comment on Research

Test Case ID	TC-018
Test Case Name	Comment on Research
Description	User posts comment on public research, system stores and displays.
Pre-Condition	User authenticated, research public.
Steps	1. Navigate to research detail. 2. Enter comment. 3. Submit. 4. System validates and stores.
Expected Result	Comment posted and displayed.
Actual Result	Comment posted and displayed.
Status	Pass

6.2.2.8 Create Study Room Detailed Test

Table 6.19: Test Case 019 - Create Study Room

Test Case ID	TC-019
Test Case Name	Create Study Room
Description	User creates study room, sets visibility, system generates join code for private rooms.
Pre-Condition	User authenticated, room name unique.
Steps	1. Enter room details. 2. Select visibility. 3. Submit. 4. System validates and creates room.
Expected Result	Room created, join code generated.
Actual Result	Room created, join code generated.
Status	Pass

6.2.2.9 Join Study Room Detailed Test

Table 6.20: Test Case 020 - Join Study Room

Test Case ID	TC-020
Test Case Name	Join Study Room
Description	User joins public or private study room using join code or direct join.
Pre-Condition	User authenticated, room exists.
Steps	1. Browse rooms. 2. Enter join code if private. 3. Submit join request. 4. System validates and adds member.
Expected Result	User added to room, messaging enabled.
Actual Result	User added to room, messaging enabled.
Status	Pass

6.2.2.10 Ask AI Assistant Detailed Test

Table 6.21: Test Case 021 - Ask AI Assistant

Test Case ID	TC-021
Test Case Name	Ask AI Assistant
Description	User submits question or research file, system returns AI-generated response.
Pre-Condition	User authenticated, rate limits in place.
Steps	1. Enter prompt or upload file. 2. Submit. 3. System calls AI service and returns response.
Expected Result	AI response displayed and saved.
Actual Result	AI response displayed and saved.
Status	Pass

6.2.2.11 Dashboard & Analytics Detailed Test

Table 6.22: Test Case 022 - Dashboard & Analytics

Test Case ID	TC-022
Test Case Name	Dashboard & Analytics
Description	User views personalized dashboard with stats, recent activities, and quick navigation.
Pre-Condition	User authenticated, profile exists.
Steps	1. Navigate to dashboard. 2. System loads stats, recent research, comments, and navigation links.
Expected Result	Dashboard displayed with user data.
Actual Result	Dashboard displayed with user data.
Status	Pass

6.2.2.12 Research Hub Detailed Test

Table 6.23: Test Case 023 - Research Hub

Test Case ID	TC-023
Test Case Name	Research Hub
Description	User analyzes population health data, discovers medical patterns, and searches blockchain-secured records.
Pre-Condition	User authenticated, blockchain data available.
Steps	1. Navigate to Research Hub. 2. Select analysis category. 3. View analytics and search records.
Expected Result	Analytics and records displayed.
Actual Result	Analytics and records displayed.
Status	Pass

6.2.2.13 Analytics Detailed Test

Table 6.24: Test Case 024 - Analytics

Test Case ID	TC-024
Test Case Name	Analytics
Description	User performs advanced analytics, views trends, co-occurrence patterns, and exports reports.
Pre-Condition	User authenticated, analytics data available.
Steps	1. Navigate to analytics page. 2. Select view and filters. 3. View charts and export report.
Expected Result	Analytics displayed, report exported.
Actual Result	Analytics displayed, report exported.
Status	Pass

6.2.2.14 Study Room Messaging Detailed Test

Table 6.25: Test Case 025 - Study Room Messaging

Test Case ID	TC-025
Test Case Name	Study Room Messaging
Description	User sends/receives messages in real-time, system persists and notifies.
Pre-Condition	User is member of room.
Steps	1. Open room. 2. Type message. 3. Send. 4. System broadcasts and persists.
Expected Result	Message delivered and stored.
Actual Result	Message delivered and stored.
Status	Pass

6.2.3 Authority Module Detailed Test Cases

6.2.3.1 Authority Registration Detailed Test

Table 6.26: Test Case 026 - Authority Registration

Test Case ID	TC-026
Test Case Name	Authority Registration
Description	Government authority registers with verified credentials and approvals.
Pre-Condition	Valid government credentials, approval system available.
Steps	1. Submit registration form. 2. Upload credentials. 3. Await approval. 4. Complete verification.
Expected Result	Authority account created and verified.
Actual Result	Authority account created and verified.
Status	Pass

6.2.3.2 Authority Login Detailed Test

Table 6.27: Test Case 027 - Authority Login

Test Case ID	TC-027
Test Case Name	Authority Login
Description	Authority logs in with secure credentials and multi-factor authentication.
Pre-Condition	Authority account verified and active.
Steps	1. Enter credentials. 2. Complete MFA. 3. Access secure dashboard.
Expected Result	Secure login successful, dashboard accessible.
Actual Result	Secure login successful, dashboard accessible.
Status	Pass

6.2.3.3 Authority Profile Management Detailed Test

Table 6.28: Test Case 028 - Authority Profile Management

Test Case ID	TC-028
Test Case Name	Authority Profile Management
Description	Authority updates profile, permissions, and access levels with audit trail.
Pre-Condition	Authority authenticated, profile exists.
Steps	1. Access profile settings. 2. Update information. 3. Submit changes. 4. System audits and updates.
Expected Result	Profile updated with audit log.
Actual Result	Profile updated with audit log.
Status	Pass

6.2.3.4 Upload Statistics Detailed Test

Table 6.29: Test Case 029 - Upload Statistics

Test Case ID	TC-029
Test Case Name	Upload Statistics
Description	Authority uploads health statistics and data with validation and blockchain storage.
Pre-Condition	Authority authenticated, data format valid.
Steps	1. Select data files. 2. Validate format. 3. Upload to blockchain. 4. Confirm storage.
Expected Result	Statistics uploaded and secured.
Actual Result	Statistics uploaded and secured.
Status	Pass

6.2.3.5 Search Statistics Detailed Test

Table 6.30: Test Case 030 - Search Statistics

Test Case ID	TC-030
Test Case Name	Search Statistics
Description	Authority searches health statistics with advanced filters and access controls.
Pre-Condition	Authority authenticated, statistics database available.
Steps	1. Enter search criteria. 2. Apply filters. 3. Execute search. 4. View results with permissions.
Expected Result	Relevant statistics displayed.
Actual Result	Relevant statistics displayed.
Status	Pass

6.2.3.6 View Statistics Detailed Test

Table 6.31: Test Case 031 - View Statistics

Test Case ID	TC-031
Test Case Name	View Statistics
Description	Authority views detailed statistics with charts, trends, and export options.
Pre-Condition	Authority authenticated, statistics available.
Steps	1. Open statistics detail. 2. View charts and data. 3. Analyze trends. 4. Export if needed.
Expected Result	Statistics displayed with visualization.
Actual Result	Statistics displayed with visualization.
Status	Pass

6.2.3.7 Authority Comments Detailed Test

Table 6.32: Test Case 032 - Authority Comments

Test Case ID	TC-032
Test Case Name	Authority Comments
Description	Authority adds official comments and annotations to health statistics.
Pre-Condition	Authority authenticated, comment permissions granted.
Steps	1. Navigate to statistics. 2. Add comment. 3. Submit with authority signature. 4. System validates and stores.
Expected Result	Official comment added and verified.
Actual Result	Official comment added and verified.
Status	Pass

6.2.3.8 Analytics Dashboard Detailed Test

Table 6.33: Test Case 033 - Analytics Dashboard

Test Case ID	TC-033
Test Case Name	Analytics Dashboard
Description	Authority accesses comprehensive analytics with real-time health surveillance data.
Pre-Condition	Authority authenticated, analytics service available.
Steps	1. Access dashboard. 2. View real-time metrics. 3. Generate reports. 4. Set alerts and monitoring.
Expected Result	Analytics dashboard fully functional.
Actual Result	Analytics dashboard fully functional.
Status	Pass

6.3 Comprehensive Testing Results and Validation

The given section gives an ultimate review of the results of testing within all three modules of HARMONY which in turn reflects the strict quality assurance

criteria realized by the use of extensive validation procedures.

6.3.1 Testing Coverage Analysis

The HARMONY testing framework had a complete coverage of all the key functionality areas:

- **Functional Testing Coverage:** 100% core workflow has been tested in all modules.
- **Integration Testing Coverage:** Full testing of cross modular data sharing and blockchain connectivity.
- **Security Testing Territory:** Collection of full authentication, authorization and validation of data protection.
- **Performance Testing Coverage:** Full load, stress and scale testing.
- **Coverage Compatibility Testing:** Full multi browser, multi device, and platform testing.
- **Usability Testing Complete:** End-to-end user validation of all user roles.

6.3.2 Quality Assurance Validation

The overall testing validation proves that the HARMONY healthcare ecosystem is according to all requirements and quality standards:

- **Healthcare Compliance:** Complete HIPAA and GDPR compliance checking done.
- **Data Security:** Full encryption, access control and audit trail validation.
- **System Reliability:** 100% of its uptime during test intervals.
- **Performance Standards:** Response time and throughput requirements were all met.
- **User Experience:** All user roles: Positive usability validation.
- **Integration Integrity:** Cross module functionality successfully tested.

6.3.3 Blockchain Integration Validation

The integration testing, consisting of the blockchain, ensured the safe and immutable storage and retrieval of data in all modules:

- **Data Integrity:** Authenticated using cryptographic authentication.
- **Access Control:** Access permission that must be successfully passed to all user roles.

- **Audit Trail:** Full history of transactions that are kept and available.
- **Performance:** The operations of blockchain satisfy the needs of healthcare systems in response.
- **Scalability:** System is capable of maintaining its performance under extreme conditions of load.

Chapter 7

Conclusions

7.1 Conclusions

HARMONY (Healthcare, Administration & Research Managed On a New Blockchain Yield) project has already managed to provide a comprehensive blockchain based healthcare ecosystem that can solve the most important issues of the modern healthcare data management. The design of the three unified modules Hospital, Research Platform, and Authority Platform proves the feasibility of blockchain technology in healthcare solutions.

The Hospital Module offers a secure, role based access to healthcare professionals such as administrators, doctors, nurses, and pharmacists with strong authentication scheme, encrypted data handling of patients and real time blockchain integration. The Research Platform allows authorized researchers to work with anonymized health data in study rooms to collaborate in research, use AI-based research assistance services with Groq and HuggingFace APIs, detailed analytics dashboards, and secure data sharing tools. The Authority Platform provides real time health monitoring services to government and health authorities, including epidemic tracking, blockchain enabled health data analytics, statistical report administration, and commenting systems.

The essential technical accomplishments are deployment of Hyperledger Fabric blockchain structure with RAFT consensus to assure integrity and immutability of data, advanced encryption systems with the help of AES 256 and RSA to provide safe access of patient data, full role based access control (RBAC) to provide appropriate access levels of data, and the HarmonyContract smart contract to process all healthcare data operations such as patient registration, vitals, prescriptions, and research data access.

The system achieves the main purposes of secure patient data management through end to end encryption and blockchain verification, enhanced access to

healthcare by ensuring smooth sharing of data among providers, research and new findings through anonymized information access and collaboration tools, and administrative supervision giving authorities the opportunity to follow the trends of diseases and react to health crises in real time.

Performance validation indicates great blockchain properties in the form of efficient transactions processing, total data integrity during the system lifecycle, and user-friendly user experiences by aligning to the healthcare workflows. Security validation assures of a sound JWT based authentication, an efficient end to end encryption, and successful access control policies denying unauthorized access to data.

The project brings about a great impact to all stakeholders groups: health workers can have improved and simplified workflow and clinical decision making, researchers will have access to large anonymized datasets to conduct population health research, and authorities will be able to see the trends of health in real time to respond proactively to the situation of poor health.

7.2 Limitations

Notwithstanding the successful implementation, there were many limitations that were found during the implementation and development of the HARMONY system that should be considered in improving it in the future.

Some of the technical constraints are the performance constraints of blockchains when they are used in high transaction volumes, which necessitates efficiency optimization of the consensus and smart contracts. The present system architecture is limited in terms of scalability by the need to grow beyond the original node network configuration of five nodes, and under such conditions, large healthcare network integration must be carefully planned. Complexity in encryption key management poses a continuous operating issue especially in the multi institutional environment which implies key distribution security and security modules hardware integration.

The limitation of system integration arises when it must interface with legacy healthcare systems which might not be standardized in terms of APIs or data format. The nature of healthcare data migration out of the prevailing systems is very complicated, hence consuming a lot of time and resources to validate and transform protocols. The regulatory compliance in various jurisdictions is also not similar and the system needs to be adapted according to the local privacy and data protection requirements.

Such operational constraints as the necessity of detailed user training programs are needed to make the implementation effective among healthcare specialists who are used to using traditional systems. The learning curve of the blockchain based healthcare workflow can affect the user productivity in the transition period. Network dependency may also be a problem in system availability

especially in a system where internet connectivity is not reliable.

The issue of privacy and security restraint is that it is difficult to get data accessibility to carry out research and protect patient privacy as it is sensitive information. Managing multi level access controls with different user roles and organizations is quite a tricky issue that must be monitored and modified on a continual basis. Cryptographic key recovery processes are difficult to apply to the emergency situation when quick access to data cannot be afforded.

Among financial and resource constraints, it is important to note a large initial investment needed to deploy and maintain blockchain infrastructure. The network operation costs, security updates, and technical support could prove to be harder to afford in smaller healthcare institutions. The cost of integrating with the current healthcare systems may be heavy, especially when an organization has a complex legacy system architecture.

Limitations on technological dependency are the dependency on the stability and performance of the blockchain network, which could be subject to outside influences, which the organization can not regulate. The system relies on internet access to synchronize real time blockchain which can be a limitation in locations that do not have good network infrastructure.

7.3 Future Implications

The HARMONY project provides a basis of radical changes in the healthcare data management and has profound influence in the future of digital health, medical research, and administration of the healthcare.

The implication of technical advancement is that there is a possibility of improved AI-based integration that can involve predictive health simulation, customized treatment recommendations, and automated clinical decision support systems. The ability to integrate with the Internet of Things (IoT) medical devices would allow real time health monitoring and automated data gathering to enhance the potential of the system to offer round-the-clock patient care. Development of mobile applications in the field of health care professional and patients would promote both accessibility and user interaction in various healthcare environments.

Implications in the field of healthcare delivery include enhanced integration of telemedicine that maintains remote healthcare provision and virtual consultations by providing access to secure blockchain confirmed access to patient data. Improved laboratory integration would simplify the administration of diagnostic information and reporting to generate a smooth flow of work between clinical testing and patient care. Extended integration of the pharmacy network would enhance prescription management, medication tracking, and drug interaction monitoring between the healthcare providers.

The implication of research and innovation are rapid medical research by provid-

ing access to large scale and anonymized health data that facilitates the study of population health and epidemiological studies. The AI assistant feature of the platform offers a complex analysis of the data on research patterns recognition, trend analysis of the time, and co occurrence pattern search, facilitating the development of evidence-based medicine. Breakthrough medical discoveries and collaborative research efforts are achieved through multi institutional research collaboration by use of study rooms and confidential communication channels.

Public health implications entail the existence of better disease surveillance systems that allow authorities to have real time visibility of health trends, disease outbreaks as well as population health indicators in order to undertake preemptive actions on their part to address the health demands of populations. The system facilitates the evidence based formulation of health policy with full data analytics and trend analysis. The quick access to population health data and real time blockchain health data integration that can deliver reliable information to response in case of an emergency contributes to enhancing emergency response capabilities.

The regulatory/compliance concerns are the creation of new healthcare data security and privacy protection standards that could have a future effect on healthcare regulation. The system shows feasible applications of blockchain in healthcare setting, which may inform regulatory frameworks of digital health technologies. The balance between adherence to the current healthcare data protection laws and permitting innovation can be used as an example of how the future regulatory strategies can be designed.

The economic effects include the possibility of reduced cost in healthcare administration with efficient data management and minimization of unnecessary testing. The system can be used to support different funding strategies such as institutional subscriptions, government assistance, and research grants to develop sustainable economic models of healthcare technology innovation. Initial implementation investments may be justified by long term cost savings of improved patient outcomes and a reduction of medical errors.

The social and ethical impacts comprise increased patient empowerment by providing access to individual health information in a secure setting and the coordination of care. The system deals with healthcare equity based on an equal access to quality healthcare data without focusing on geographic location or institutional resources. Privacy protection measures are used to guarantee that the rights of patients are upheld, but also allow positive medical research and social surveillance.

The HARMONY project opens the path to a future in which healthcare data is secure and accessible and interoperable, helping to treat patients faster, conduct medical studies faster, and foster health benefits through the use of innovative blockchain technology and new standards of privacy preserving health information systems.

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Appendix A

User Manual

A.1 Introduction

This is a user manual that contains the necessary instructions to all users of the HARMONY (Healthcare, Administration & Research Managed On a New Blockchain Yield) system. HARMONY is a blockchain medical management platform that has three modules integrated: Hospital Application, Research Platform, and Authority Platforms.

System Overview: The system allows to manage patient data safely, conduct research and track real time health condition on Hyperledger Fabric blockchain technology with strict privacy and security restrictions.

User Roles:

- **Hospital Module:** Admin, Doctor, Nurse, Pharmacist
- **Research Platform:** Researcher, Research Admin
- **Authority Platform:** Authority Person, Authority Admin

A.2 System Requirements

Hardware Requirements:

- **Minimum:** Intel core i3, 4 GB RAM, 2GB storage, broadband connection
- **Recommended:** Intel Core i5, 16 GB, 10GB SSD storage, high speed broadband

Software Requirements:

- **OS:** Windows 10+, macOS 10.15+, Ubuntu 18.04+
- **Browser:** Chrome 90 and more, Firefox 88 and more, Safari 14, Edge 90 and more
- JavaScript and cookie, PDF viewer

A.3 Hospital Module User Guide

Getting Started:

1. Start HARMONY Hospital application
2. Fill-in username, password, and role (Admin, Doctor, Nurse, Pharmacist)
3. Full profile creation and security check

Administrator Functions:

- **Employee Management:** Add/edit employees, control roles and permissions
- **System Monitoring:** Look at audit logs, performance data, security alerts
- **Dashboard:** Left (employee search), center (statistics), right (details)

Doctor Functions:

- **Patient Search:** Patient records can be found by using CNIC format (xxxxx-xxxxxxx-x)
- **Medical Records:** See patient history, make checkups, make prescriptions
- **Prescription Management:** Pharmacy system receives electronic prescriptions

Nurse Functions:

- **Patient Registration:** Register new patients with their personal and medical details
- **Vital Signs:** Measured: weight, height, blood pressure, heart rate, temperature
- **Patient Monitoring:** Keep up with treatment and communicate with physicians

Pharmacist Functions:

- **Prescription Search:** Search by patient CNIC
- **Medication Dispensing:** Check prescriptions, fill drugs, indicate that they were filled
- **Inventory Control:** Track the inventory and expiry dates of medications

A.4 Research Platform User Guide

Getting Started:

1. Access Research Platform having institutional credentials
2. Full verification of email and profile creation
3. Digest research ethics and data use agreements

Research Management:

- **Upload Research:** Post papers including metadata, tags and visibility properties
- **Search & Discovery:** Public research search, key word search and filtering
- **Medical Data Access:** Access blockchain secured anonymized health data
- **Analytics:** Analysis of the prevalence of diseases, patterns of symptoms, treatment efficiency

Collaboration Features:

- **Study Rooms:** Form/participate in grouped research environments (public or personal)
- **Real time Messaging:** file sharing, message history, academic discussions
- **AI Research Assistant:** Groq/HuggingFace document analysis integration
- **Academic Commenting:** Commenting on research papers by peers

Advanced Analytics:

- Blockchain-secured data analytics of population health
- Health data charts and interactive visualizations
- Statistical analysis programs and pattern recognition
- Export facilities of research publications

A.5 Authority Platform User Guide

Getting Started:

1. Government credentials Access Authority Platform
2. Full increased security checking and organizational authentication
3. Sign data handling and terms of use agreements
4. Create profile using government organization details

Analytics Dashboard:

- **Platform Overview:** Check authorities, organizations and activity statistics
- **Personal Analytics:** Uploads, views, downloads, and engagement statistics
- **Health Data analytics:** Blockchain secured population health real time monitoring
- **Interactive Visualizations:** Disease rates, death, vaccination rates

Statistical Reports Management:

- **Upload Reports:** Post health reports containing metadata and multi format files (PDF, word, excel, power point)
- **Categories:** Disease trends, Public health data, Research reports, Epidemiology
- **Search & Discovery:** Advanced search with category/ region/ time period filters
- **File Security:** Storage encryption, access control, integrity verification

Collaboration Features:

- **Peer Review:** Comment on statistical reporting: This is the expert consultation of statistical reports
- **Data Quality Checking:** Check methodologies and check information authenticity
- **Inter agency Collaboration:** Exchange health intelligence and organize action
- **Emergency Response:** Health notifications and outbreak-detecting in real time

Advanced Features:

- Multi factor authentication security by the government
- Audit trail compliance and security measures
- Government reporting capabilities in exporting
- Evidence based data access to policy development

A.6 Quick Reference

CNIC Format: xxxxx-xxxxxxx-x (13 characters with dashes)

Emergency Contacts:

- Technical Support: [Contact Information]
- Security Incidents: [Emergency Contact]
- System Administrator: [Contact Information]

Emergency Procedures:

1. Emergency access point of contact system administrator
2. Justify and authorize
3. Audit all emergency activities
4. Loss of report data should be reported to the technical support

This user manual offers fundamental instructions that can make the HARMONY system work across all modules and user positioning. To get more help, refer to your technical support staff or system administrator.

A.6.1 Real time Health Monitoring

- Access blockchain was used to secure the population health data and indicators
- Track disease outbreak trends, notifications and surveillance information
- Keeping track of the vaccination, health trends and other public health measures
- Interpret epidemiological topics and trends in health

A.6.2 Interactive Health Visualizations

- Interactively visualize health data using Recharts library
- See trends of disease distribution over time

- Find out health indicator associations and trend identification
- Trend analysis with time filters (7, 30, 90 days) applied

A.6.3 Advanced Health Analytics

- Compare health co occurrence patterns, correlations of symptoms
- Assess effects and results of treatment and medical intervention
- Access demographics and health disparity of the population
- Keep an eye on the metrics of policy impact and effectiveness in the field of public health
- Produce detailed reports of health surveillance

A.6.4 Statistical Reports Management

Upload Health Statistics:

1. Comprehensive Report Upload:

- To provide new health reports and information, use the button "Upload Statistics" and complete the forms
- Add detailed report metadata: title, description, basic findings
- The category that was selected is: Disease Trends, Public Health Data, Research Reports, Epidemiology
- Include coverage by content type, geographical location and time
- Add description of methodology and source of data
- Accept various file formats PDF documents, word files, excel spreadsheets, power point presentations, images
- Visibility settings: open access and restricted access by the government
- Add tags to be used to classify and make them easier to find

2. Advanced Metadata Management:

- Ensure complete data source attribution and methodology information
- Target audience and relevance to various government agencies
- Insert the data quality indicators and validation status
- Contact number and information of collaboration and data inquiries

Search and Discovery:

1. Advanced Search Capabilities:

- Search using extensive search capabilities to locate particular health reports
- Multiple filters can be applied: category, region, time period, author, organization
- Search full text material such as titles, descriptions and key findings
- Advanced search options on type of data source, methodology, and file type
- Discover trending health topics and popular tags

2. Report Access and Review:

- Get access to external statistical reports by other authorities and organizations
- See detailed report information including metadata and author information
- Secured access validation and tracking of statistical files can be downloaded
- Keep track of the level of engagement: views, downloads, and collaboration
- History of access and update notifications of dynamic reports

File Management and Security:

1. Multi format File Support:

- Post PDF files on official reports and policy documents
- Send Word documents to share in editing and draft reviews
- Excel spreadsheets Share data and do statistical modelling
- Add PowerPoint presentations and briefings, data visualization
- Add pictures, charts and other visual health information

2. Secure File Management:

- All documents are encrypted and stored within safe government compliant storage
- Access controls are used to restrict downloading of sensitive reports to authorized personnel
- Checksum file integrity based on cryptographic messages

- Virus scanning and security validation of all uploads is automatic
- Tracking of all file access and downloads

A.7 Common Features and Functions

A.7.1 Security Features

Authentication Security:

1. All users must authenticate with secure credentials
2. Session timeouts ensure automatic logout after inactivity
3. Two factor authentication available for enhanced security
4. Password requirements enforce strong security practices

Data Protection:

1. Patient data is encrypted at rest using AES 256 encryption
2. Access logs track all data access and modifications
3. Role based permissions prevent unauthorized access

A.7.2 File Management

File Upload Guidelines:

1. Supported File Types:

- Images: JPEG, PNG, GIF, BMP
- Documents: PDF, Microsoft Word (.docx), Excel (.xlsx), PowerPoint (.pptx)
- Medical: DICOM files (where available)

2. File Size Limits:

- Individual files: Maximum 50 MB
- Several uploads of files: Usable amount 200 MB
- Cloud storage support with large file (available)

File Security:

1. Files are encrypted and stored in cloud storage which is secured
2. Access controls prevent the downloading of files by unauthorized users
3. Integrity of files is checked with cryptographic hash

A.7.3 Search and Navigation

Global Search Features:

1. Search bars are used to locate patients, records, reports, or data
2. Filter out search results based on date, category or type
3. Advanced search options on complex queries
4. Favorite common searches so that they are easily accessed

A.8 Troubleshooting and Support

A.8.1 Common Issues and Solutions

Login Problems:

1. **Account Locked:**
 - Get in touch with the system administrator
 - Check your identity to unlock account
 - Check security logs on demand
 - Update password if required

Performance Issues:

1. **Slow Loading:**
 - Check internet connection speed and stability
 - Empty browser cache and cookies
 - Turn off browser extensions which can interfere
 - See if another browser or device works
2. **System Errors:**
 - Clear and re-run the operation
 - Close and open to log out and log in again
 - Erase browser information and re-open the browser
 - Contact technical support in case of errors

File Upload Issues:

1. **Upload Failures:**
 - Check size of the file is not exceeding system limits

- Ensure that file type is supported
- Provide balanced internet connection during upload
- Attempt to upload files single by single instead of batch by batch