UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE)

DEVELOPMENT OF A CLINICAL DATA HARMONIZATION SYSTEM TO IMPROVE HEALTHCARE SERVICES

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A Dissertation Submitted to the Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE), University of Rwanda as partial fulfilment of the requirements for the Master's Degree in Biomedical Engineering.

Supervised by:

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DECLARATION

I, NTIHINYURWA Jean Bosco, declare that this dissertation entitled “DEVELOPMENT OF A CLINICAL DATA HARMONIZATION SYSTEM TO IMPROVE HEALTH CARE SERVICES” is my original work based on research and prototype and has not been submitted for any other degree or professional qualification.

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CERTIFICATE

This is to certify that the project entitled "DEVELOPMENT OF A CLINICAL DATA HARMONIZATION SYSTEM TO IMPROVE HEALTH CARE SERVICES" is a record of original work done by NTIHINYURWA Jean Bosco 220012481, a MSc. Degree student in Biomedical Engineering.

This work has been submitted under the guidance of Prof. TWIZEYE Celestin and Dr. Morufu O. IBITOYE.

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ACKNOWLEDGMENTS

The writing and conducting this thesis would not have been possible without the contributions, encouragement and supports from many people in all corners of my life.

First and foremost, my special thanks go to almighty God for his protection during this thesis and the whole period of my life.

I would like to thank my beloved families for their encouragement, moral support and prayers during the whole period of my studies.

My special thanks also go to University of Rwanda/ Regional Center of excellence in Biomedical Engineering and e-health who provided the required knowledge, skills and financial support for writing this thesis.

I am absolutely thanking my supervisors **Prof. TWIZEYE Celestin** and **Dr. Morufu O. IBITOYE** for their advices, encouragements and guidance during my thesis.

Finally, special thanks go to all my lectures who gave me helpful package of theoretical and practical knowledge, your help is warmly acknowledged.

ABSTRACT

A clinical data harmonization system between different healthcare providers, was developed, to ensure that relevant information about a patient's medical history, diagnoses, treatments, and medication is available to all involved healthcare partners before any service delivery. The author put an emphasis on this system due to the prevalent use of in-house patient record systems by local healthcare providers. These systems hinder healthcare practitioners' ability to access information promptly, which is crucial for timely and informed decision-making. The author's objective is to develop a clinical data harmonization system that improves healthcare services delivery by basing to the patients' history before any therapeutic service. The goal is to hasten the diagnosis process though quick decision making and to reduce healthcare costs through circumventing the cost and time wastage through duplicated tests and appointment entreaties. The system needs assessment was conducted on 42 respondents having served at different level of healthcare facility. Among the respondents, 38.1% were served through an inhouse data sharing system, 61.9% were served through paper works and compact disc in the same healthcare facility, while no one (0%) was served through a harmonized system between two or more healthcare facility. The results were achieved through reviewing literature to collect secondary data, surveys to collect primary data and engineering method to design, develop and test the prototype. The developed system enables sharing and viewing patient's medical record both within and outside the healthcare facility by providing a user identification (Names and passcode) which is generated at the first time he/ she is requesting the medical service.

Keywords: *Clinical data*; healthcare providers; data harmonization; data records.

LIST OF ACRONYMS

CDHS: Clinical Data Harmonization System
CDP: Clinical Data Pull
DICOM: Digital Imaging and Communications in Medicine
DHIS: District Health Information System
DHP: Data Harmonization Pipeline
EHR: Electronic Health Records
FHIR: Fast Healthcare Interoperability Resources
HIS: Health Information Systems
HIV: Human Immunodeficiency Virus
HL7: Health Level Seven
HTTPS: HyperText Transfer Protocol Secure
ICT: Information and Communication Technologies
IHSSP: Integrated Health Systems Strengthening Project
IPMIS: Integrated Patient Management System
MedRec: Medication reconciliation
MoH: Ministry of Health
RHIS: Routine health information systems
R-HMIS: Rwandan Health Management Information System
WCO: World Customs Organization

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CHAPTER 1. GENERAL INTRODUCTION

1.1 Introduction

In order to guarantee that pertinent details on a patient's medical history, diagnosis, treatments, and medicines are available to all engaged healthcare professionals, a clinical data harmonization system attempts to disseminate clinical data among various healthcare providers. This improves continuity of care, lowers the chance of medical errors, and allows for more informed decision-making. Sharing clinical data fosters interoperability between healthcare systems and electronic health records (EHRs). It decreases the need for unnecessary tests and procedures, saves paperwork, and increases the efficiency of healthcare delivery. This may result in cost reductions for health services [1][2].

Clinical harmonization systems are essential frameworks in modern healthcare, designed to standardize and integrate diverse clinical data and practices across various healthcare settings. These systems aim to ensure consistency, accuracy, and interoperability of clinical information, which is critical for improving patient outcomes, enhancing the quality of care, and facilitating research and development.

Clinical harmonization systems rely on standardized terminology, data formats, and processes. This standardization enables data sharing between various healthcare providers, laboratories, and research institutes. These systems solve the issues provided by divergent and fragmented healthcare information systems by harmonizing clinical data, which frequently impedes efficient and effective patient treatment. Clinical harmonization systems consist of:

1. **Standardized Terminologies**: Utilizing universally accepted medical terminologies and classifications, such as the International Classification of Diseases (ICD) and the Systematized Nomenclature of Medicine – Clinical Terms (SNOMED CT), to ensure that clinical information is uniformly understood and applied.

2. **Interoperable Data Formats**: Implementing common data formats and exchange standards, such as Health Level Seven (HL7) and Fast Healthcare Interoperability Resources (FHIR), to enable the smooth transfer and integration of data across different systems and platforms.

3. **Regulatory Compliance**: Ensuring adherence to national and international regulatory requirements, such as the Health Insurance Portability and Accountability Act (HIPAA) in the United States and the General Data Protection Regulation (GDPR) in Europe, to protect patient privacy and data security.

4. **Clinical Protocols and Guidelines**: Developing and promoting the use of evidence-based clinical protocols and guidelines to standardize patient care practices and reduce variability in treatment outcomes.

5. **Data Integration and Analytics**: Leveraging advanced data integration and analytics tools to aggregate and analyze clinical data from multiple sources, providing valuable insights for clinical decision-making, population health management, and clinical research.

In this thesis, the clinical data harmonization system is developed to allow healthcare practitioners to access previous clinical data with the permission of the patient they are taking care of for the purpose of keeping patents' data privacy and avoiding the use of the shared data against the patients. The doctor has privileges to update the data based on the client's current status, but he is not allowed to delete or modify the previous data.

1.2 Problem statement

Most healthcare providers use the stored healthcare data records in their own systems, which makes it impossible to access the data outside its boundaries as a result, healthcare practitioners' capacity to access information in a timely manner and make informed decisions is limited. In this current closed system, if a patient seeks treatment at two different healthcare institutions, each is expected to start a file for the patient and carry out standard processes. These treatments will be repetitious, particularly for chronically ill patients, or will necessitate the administration of similar tests multiple times, increasing the cost and duration of healthcare services.

1.3 Research Questions

For the success of this study the author is asking himself the following questions:

1. What are the key features and technologies required to develop an effective digitalized patient data recording and management system that improves healthcare services?
2. How can an efficient system be developed to facilitate the exchange of patient data between different healthcare providers?
3. What are the most effective design and implementation strategies for creating a communicative reporting system that promptly identifies and addresses alarming issues in clinical services?

1.4 Objectives

1.4.1 General Objective

This project aims to develop a clinical data harmonization system that will improve healthcare services delivery by basing to the patients' history before any therapeutic service and diagnostic decision.

1.4.2 Specific Objectives

To achieve the general objective of this project, the following specific objectives are used as guiding points:

1. Develop a digitalized patient data recording and management system
2. Create the system enabling exchange of data between different healthcare providers.
3. Establish a communicative reporting system for alarming issues in clinical services

1.5 Study Scope

This study focused on designing and building a system in which patients' data are recorded, managed and shared to different healthcare providers when needed. The prototype consists of three systems each one assigned to the specific healthcare and the data in any one of these systems are shared among others but with authentication verification.

1.6 Significance of the Study

The system has a great impact on the improvement of health services as it helps in accurate decision making on different diagnostics cases, reduces the cost of healthcare services and provides real time data to the central healthcare authorities for awareness of abnormal expansion of illness with a specific region, accurate planning and proper decision making. Clinical data harmonization involves the process of reconciling differences in data formats, structures, and semantics to enable interoperability and comparability across different datasets.

The significance of CDHS can be observed in several domains:

1. Research advancement: Through the integration of data from many sources, CDHS facilitate large-scale data analysis and secondary research, allowing researchers to gain important insights and hasten scientific discoveries [3].

2. Clinical trials and drug development: Harmonized clinical data are essential for multicenter clinical trials, evaluating the efficacy of treatments, and guaranteeing patient safety during the drug development process [4].

3. Healthcare quality improvement: CDHS supports patient outcomes assessment, population health management, and quality improvement programs by harmonizing data from electronic health records (EHRs).

1.7 Organization

Chapter one gives the introduction to the thesis and serves as a roadmap for the reader, providing an overview of the topic, its significance, hypotheses being addressed, and the structure of the thesis itself. Chapter two provides a literature review for my thesis by examining existing research, theories, and scholarly works relevant to the clinical data harmonization system. Chapter three deals with methodology to outline the systematic process that employed to conduct this study, gather data, analyze information, and draw conclusions. Chapter four is about presentation and analyses of the results and findings from implemented system and finally chapter five discusses challenges, recommendations and conclusions from the research study.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

Routine health information systems (RHISs) may perform better with the use of data harmonization, a digital innovation based on technology. Large data bases with routine health information can be integrated and organized with its assistance. Data harmonization interventions, when planned, developed, and implemented, have the ability to improve RHISs to high-quality and pertinent information that can support choices, actions, and changes at all levels and components of the health system [5].

According to the reviewed literature, it is noticed that the Rwandan health information system consists of different platforms for data gathering, processing, analysis and storage for planning and informed decision making from the health centers to the central level. These platforms are interoperable one to another for the purpose of data sharing and easy coordination of related data. This has improved the reporting of data and events at each level and facilities are using this data to tailor their services to better meet the requirements of their clients, resulting in a stronger, more resilient health system and a healthier population.

Despite having an informed health system, Rwanda health information system still have a problem of sharing data from one facility to another outside the catchment area in terms of personnel data and individual health status that can be used for therapeutic and diagnostic informed decision making for the sake of avoiding duplicated tests, delays in diagnosis, treatment errors, inappropriate medical interventions among others.

2.2 Historical background of Rwanda's Health Management Information System

The Rwandan Ministry of Health collaborated with the Integrated Health Systems Strengthening Project (IHSSP) to improve and organize the health information system, in accordance with an agreement reached at a conference attended by health ministers on Research for Health in Africa, held in Algeria, to guide the improvement of their health information management systems. When IHSSP was founded in 2009, the ministry had numerous systems to collect data from the country's health services, but the systems used to aggregate and analyze the information were poor and not interoperable [6] [7][8][9].

2.2.1. The Rwandan Health Management Information System (R-HMIS)

In collaboration MoH with IHSSP, the Rwandan Health Management Information System (R-HMIS) was built and rolled out nationally in 2012 with the purpose of improving the system in different areas including data entry, storage, aggregation and a user-friendly for viewing and analyzing all facilities' information onsite, in real time [6][7][8].

The free and adaptable web-based software platform DHIS 2 allows health centers to enter data directly into the national database via the R-HMIS. Furthermore, with a single mouse click, they may view charts and graphs that show patterns in their data over time. By streamlining and automating the monthly reporting of service data, the national average for completeness of reporting increased from 88% in 2008 to 95% in 2012 [8][7][6].

The allows health centers

All health centers data entry directly into the national database via the R-HMIS is allowed though a free and adaptable web-based software platform DHIS 2. Furthermore, with a single mouse click, they may view charts and graphs that show patterns in their data over time. The national average for completeness of reporting increased from 88% in 2008 to 95% in 2012 due to the streamed and automated monthly service data reports.

Since the efficacious launch of the R-HMIS, many new reporting modules have been integrated into the DHIS 2 platform, including annual health facility infrastructure reporting, quarterly tuberculosis program reporting, monthly HIV program reporting, quarterly reporting from nongovernmental organizations working with most-at risk populations for HIV prevention, case-based reporting on neonatal, child, and maternal death audits, and case-based tracking of multidrug resistant pat [6][7][8].

2.2.2. The National Data Warehouse

The Ministry of Health realized that the country couldn't completely utilize the power of their data unless numerous other health databases were better integrated. To facilitate interaction across the ministry's databases, IHSSP returned to DHIS 2 and, in partnership with the ministry, created the Rwandan Data Warehouse, a one-stop shop for essential health sector statistics. The Data Warehouse gathers around 200 indications from the R-HMIS and four other databases. Census, demographic, and health survey data are included when they become available. The Data Warehouse provides the ministry with a detailed overview of the health care situation across the country [6][7][8].

At present, the country’s health system features a well-organized and effective system for gathering, reviewing, and analyzing health data at all levels. This system equips the government with the necessary information to swiftly adapt and respond to changes or challenges in its environment. Additionally, it offers a more extensive dataset for strategic planning and policy development. Leveraging this data, IHSSP supported the government in crafting strategic plans and policies that would guide the Rwandan health system for years into the future [6][7][8].

2.2.3. Key components of a data sharing system

Data Sources: These are the healthcare facilities and systems where clinical data is generated. This includes hospitals, clinics, laboratories, imaging centers, and other healthcare providers. The data sources consist of databases as centralized or distributed databases that store the data to be shared, data lake as large repositories that can store structured, semi-structured, and unstructured data and APIs as interfaces that allow different systems to interact and exchange data.

Data Ingestion: This component is responsible for collecting and importing data from various sources into the data sharing system. It should support various data formats and standards, such as HL7, FHIR, and DICOM, to ensure interoperability.

Data Storage: The system should have a robust database or data repository to store the incoming clinical data securely. Data should be organized in a structured manner for easy retrieval and analysis.

Data Security: Security is paramount in healthcare. Implementing access control, encryption, and authentication mechanisms to protect patient data from unauthorized access or breaches is crucial.

Data Integration: This component ensures that data from different sources can be harmonized and integrated into a single, consistent format. Data mapping and transformation tools are often used to achieve this.

Data Exchange Protocols: Utilize secure communication protocols, such as HTTPS, for transmitting data between systems. Implement message queuing or API-based data exchange mechanisms.

User Interfaces: Create user-friendly interfaces for healthcare professionals to access and manage data. These interfaces should provide data visualization and reporting capabilities.

Data Backups and Disaster Recovery: Regularly back up the data and have a disaster recovery plan in place to prevent data loss in case of system failures or disaster [5].

2.3. Types of Data Models

High-level conceptual data models offer a way to represent data that aligns closely with how people naturally understand and perceive it. A common example is the entity-relationship model, which relies on key concepts like entities, attributes, and relationships. An entity represents a real-world object, such as an employee or a project. Attributes define the properties of these entities, such as an employee's name, address, and birthdate. Relationships, on the other hand, illustrate associations between entities; for instance, the relationship between an employee and the various projects they work on. Record-based logical data models provide notions that people can grasp while remaining relatively close to how data is stored in computers. Relational, network, and hierarchical data models are three well-known examples of this sort of data model [5].

2.4. Classification of Database Management Systems

Database management systems can be categorized according to several factors, including the data model, database distribution, and the number of users. The most common types of DBMS software include relational, distributed, hierarchical, object-oriented, and network models. A distributed DBMS is a set of logically interrelated databases distributed over a network that is managed by a centralized database application. This type of DBMS synchronizes data periodically and ensures that any change to data is universally updated in the database.

A hierarchical database is a data architecture in which data is stored as records and structured into a tree-like structure, also known as a parent-child structure, with one parent node and several child nodes linked together. Because of the hierarchical database structure, a parent record may have several child records, but each child record can only have one parent record. Data in records is stored in the form of fields, with each field containing only one value. To get hierarchical data from a hierarchical database architecture, you must first traverse the entire tree, beginning with the root node. Hierarchical database models are simple, but lack flexibility [10][11].

The network database architecture accommodates more complex relationships by allowing each child to have many parents. Entities are grouped into a graph that can be accessed via several paths. It is built on a network data paradigm, which enables each record to be linked to many primary and secondary records. Network databases enable you to build a customizable model of the relationships between entities.

Relational database management systems (RDBMS) are the most popular data model because of its user-friendly interface. It is a digital database based on the relational model, which organizes data in sets of tables with columns and rows. The rows, also known as records, represent a collection of related values, and each row is identified by a unique key. Each column holds attributes of a specific data type, and each record typically has a value for each attribute [10][11].

The data structures are what distinguish relational from hierarchical databases. A relational database stores data in tables and assigns a unique identification to each entry, whereas a hierarchical database architecture is tree-like. A relational database structure allows you to easily identify and access data in relation to other data points in the database. The tables are separate from the physical storage structures, therefore database managers can alter the physical data storage without having to rebuild the database tables [10][11].

Object-oriented models store data in objects instead of rows and columns. It is based on object-oriented programming (OOP) that allows objects to have members such as fields, properties, and methods. Data is created, modeled, and stored as objects, which are self-contained units that contain both data and the operations or methods that can be performed on that data [10][11].

2.5. Data Harmonization Process Steps

Data harmonization is an iterative process made of steps such as capturing, defining, analyzing, and reconciling regulatory information requirements as shown in the figure 2.1. [12].

Data capture is the process of creating an inventory of the regulatory authorities' requirements. This can be performed by, say, reviewing agency forms, automated system data needs, and rules. Defining the information requirements is crucial. While information is identified by name, it is more crucial to define the data element and what information is transmitted by using it. Analyzing is the process of analyzing the information, consisting of gathering similar data element names and having a full understanding of the definition and the information required, while reconciling is the final step, in which there is an agreement to use one data element name, a common definition, common code, and standard messaging, reconciled with the WCO Data Model standard [13] [4] [14][15].

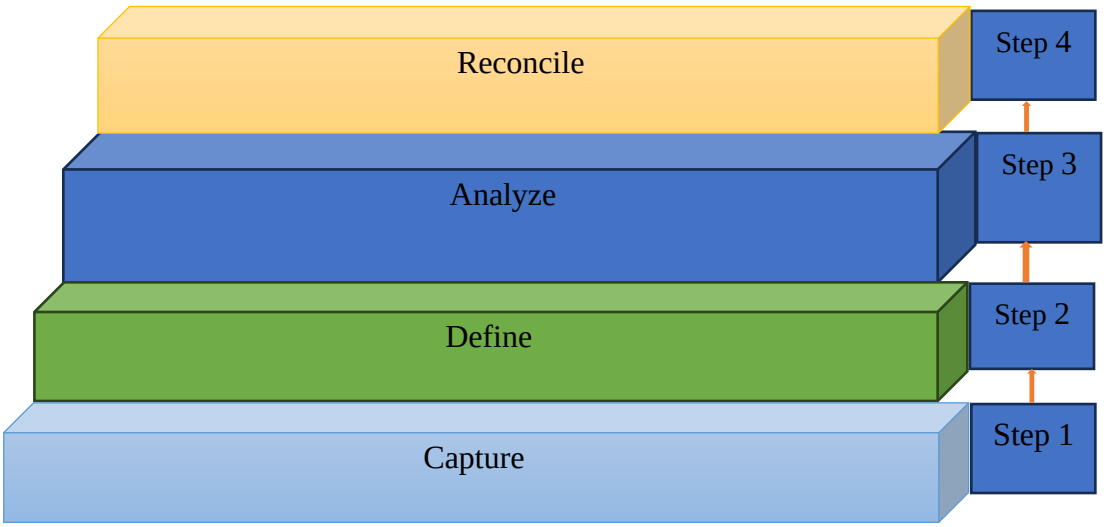

Figure 2. 1. Data harmonization process

2.6. Related works

MedRec: Using Blockchain for Medical Data Access and Permission Management

This study proposes MedRec, a unique, decentralized record management system for EMRs that uses blockchain technology. The technology provides patients with a complete, immutable log and easy access to their medical information across providers and treatment settings. MedRec manages identification, secrecy, accountability, and data sharing using unique blockchain capabilities, all of which are critical concerns when dealing with sensitive information. A modular architecture interfaces with providers' existing, local data storage options, improving interoperability and making our system more convenient and adaptable. Medical stakeholders (researchers, public health authorities, etc.) are urged to join the network as blockchain "miners". This grants individuals access to aggregated, anonymised data as mining rewards in exchange for maintaining and safeguarding the network through Proof of Work. MedRec thus facilitates the development of data economics [16].

Interoperability in Healthcare

This research investigates the distinction between social interoperability and normal interoperability. Furthermore, an inquiry is done to discover how social interoperability works in practice and the challenges it offers to healthcare. We were able to investigate ‘social' interoperability by conducting a literary survey on the meaning of interoperability and its social version, as well as using case studies. Interviews were conducted as part of the observation procedure in each case. The similarities and differences between the definitions of interoperability and social interoperability were determined through a literature review. The investigation of five specific situations led to a better understanding of social interoperability in practice. The investigations undertaken revealed some important issues for health information systems that do not achieve social interoperability [17].

Influence of Health Information Systems on Services Delivery in Public and Private Health Facilities: A Systematic Literature Review

This paper focuses on theoretical aspects of HIS and the possible benefits for improving service delivery. Challenges inhibiting successful utilization are also discussed, as are the hazards associated with limited deployment. As part of our documentary review strategy, we used a variety of search engines and databases to collect material from peer-reviewed publications and conference papers. Keywords such as 'health sector' and'services delivery' were used to locate material about quality health care The review focused on content that was published in English. The implementation of health information systems (HIS) that use information and communication technologies (ICTs) has resulted in significant advancements in healthcare service delivery. HIS plays an important role in ensuring economical and trustworthy healthcare service delivery, making it crucial to the health industry. Furthermore, HIS is crucial to the efficient and effective delivery of healthcare services in healthcare facilities [18].

Harmonization of detailed clinical models with clinical study data standard

Sharing and integrating data between clinical research data management systems (CDMS) and electronic health record (EHR) systems is challenging. To tackle this challenge, there is increasing interest in utilizing the Detailed Clinical Modeling (DCM) technique across various scenarios. The SHARPn project, funded by the Office of the National Coordinator (ONC), has employed Intermountain Healthcare's Clinical Element Models (CEMs) to standardize patient data from electronic medical records. This study aims to discuss our initial efforts to align the SHARPn CEMs with CDISC (Clinical Data Interchange Standards Consortium) clinical study data standards. We focused on three broad areas: demographics, lab tests, and medications. A panel evaluation was conducted on each data element derived from the CDISC templates and SHARPn CEMs. We identified a set of data items common to both clinical research and secondary use settings and explored remaining challenges in harmonization. The authors believe that the findings will be valuable for establishing new requirements for the DCM modeling community and ultimately enhancing semantic interoperability between systems for both clinical research and secondary use [19].

A Model for improving interoperability of healthcare systems in a distributedenvironment

An enhanced interoperability model for accessing and sharing patient health records was developed, allowing medical information to be shared across two or more dispersed healthcare systems via the modelled application. Dealing with the numerous obstacles of standardized health care data across several institutions while ensuring privacy and security concerns are satisfied makes for a tough interchange of information. To successfully address this issue, this model presents an open design that allows diverse health care systems to integrate into a single platform. This model attempts to address the challenges of sharing patient health records between two or more health care providers, which have been largely due to the complexity of the healthcare domain, standardization challenges, legacy systems, legal challenges, resistance to change, privacy and security, by making the system open so that any healthcare system can be plugged into it and facilitate data sharing and access. The study used agile development methodology, which allows for quick iterations and frequent releases while incorporating user feedback. Furthermore, the importance of developing interoperable distributed healthcare systems cannot be overstated because it offers numerous benefits such as secured access to patient's medical information in multiple formats and secure file sharing, resulting in reduced cost for both patient and hospital [20].

Clinical Data Acquisition Standards Harmonization (CDASH)

The Clinical Data Acquisition criteria Harmonization (CDASH) Standard Version 1.0 describes the suggested basic criteria for collecting clinical trial data. his document is designed for professionals involved in the planning, collection, management, and analysis of clinical trials and data. This includes roles such as Clinical Investigators, Medical Monitors, Clinical Research Associates (Monitors), Study Coordinators, Data Managers, Statistical Programmers, Biostatisticians, Drug Safety personnel, and Case Report Form (CRF) designers, among others. Sponsors must determine which additional data fields are necessary to meet the specific requirements of a study while adhering to regulatory and acceptable business standards. Sponsors will need to add therapeutic area (TA)-specific data fields to the CDASH recommendations until they are standardized to meet their protocol-specific criteria. The CDASH standards are integral to the Clinical Data Interchange Standards Consortium's (CDISC) Technical Road Map, which seeks to realize the vision of creating a unified set of standards that align with CDISC's Mission and Strategy. These standards have been and will continue to be developed to streamline various processes in medical research, ranging from the creation of clinical research protocols to reporting, regulatory submissions, data warehousing, archiving, and post-marketing studies or safety surveillance [21].

Harmonization Information Trade-Offs for Sharing Individual Participant Data in Biomedicine

This paper examines the implications of FAIR for data harmonization, which is a critical step in pooling data for IPD analysis. When it comes to data management, there is sometimes a fine line between preserving consistency and losing essential information. The discussion paper will conclude with an outline of how to balance trade-offs and harmonization. The capacity to properly manage harmonized datasets will be critical for research communities seeking to make breakthrough findings with big data or cutting-edge analytic technologies like machine learning and artificial intelligence. By emphasizing the value of scientific evidence in biomedical research, there is a potential to shift away from storytelling-based publishing products to one where quality work is evaluated based on trustworthy primary datasets[22].

A Standardized Clinical Data Harmonization Pipeline for Scalable AI Application Deployment (FHIR-DHP): Validation and Usability Study

The authors have developed a Data Harmonization Pipeline (DHP) capable of processing clinical datasets by adopting the widely acknowledged FHIR-data standards in this article. They went on to validate their design by using real-life data from the Medical Information Mart for Intensive Care IV database. Observations have demonstrated that the FHIR-DHP workflow can efficiently convert 'raw' hospital records into a standardized and AI-friendly data format. Extracting information from hospital databases using queries is a fundamental processing step in our pipeline, which is then transformed using the map-to-FHIR feature. It is then syntactically validated and uploaded to a specialist patient model database before being converted into an artificial intelligence-compatible file. The detailed implementation of FHIR-DHP was demonstrated with clinical diagnosis records as an example. The study concluded that this approach enables scalable and focused modeling of heterogeneous clinical information. By boosting interoperability and promoting cooperation among healthcare professionals, FHIR-DHP provides a milestone toward improving patient care both in clinical routine and for medical research [23].

Harmonizing and linking biomedical and clinical data across disparate data archives to enable integrative cross-biobank research

This study describes three case studies in which samples and sample descriptions are linked to allow for global searching of available samples for research. The cited use cases encompass numerous efforts, including but not limited to: The ENGAGE Consortium, which includes over 39 cohorts from around Europe and focuses on genetic and genomic epidemiology research, and the SUMMIT Consortium, which intends to identify surrogate markers connected to both micro and macro vascular problems caused by new diabetic treatments. Finally, an ongoing pilot project involves the integration of data from the Swedish Biobank and Health Registry. The Sample Availability (SAIL) approach allows researchers to successfully link their data by first generating standardized variables, then annotating and giving searchable material on specimen availability from individual biobanks for different phenotype groups. This study uses classified availability data to alleviate privacy concerns associated with handling real values. It illustrates that standardized and annotated records of data availability in diverse biological archives can play a vital role in exchanging information among biobanks during the pre-analysis stage of a project [24].

Patient Data Integration: A Panacea for Effective Healthcare

This study introduces an integration platform known as the Integrated Patient Management System (IPMIS) for handling clinical and historical patient information. Despite the availability of outstanding medical facilities worldwide, the inability to share vital clinical information with other healthcare experts has resulted in delays in necessary treatment. Furthermore, the difficulty in retrieving critical information records such as historical diagnosis exercises, compounded by disparately located medical records storage facilities, has trapped medical personnel in making uninformed decisions about patients' diagnoses, necessitating the development of a robust solution-the integrated Patient Management Information System (IPMIS). The IPMIS provides various benefits to patients and healthcare providers, including faster processes, centralized data management, enhanced patient care delivery through prompt information sharing during referrals, and effective decision-making, among others. Furthermore, the platform includes a messenger service that notifies the receiving hospital of a referral while also informing the patient about his new healthcare facility. The IPMIS is now deployed at Federal Teaching Hospital in Nigeria, and reports indicate that success rates are high [25].

Data Harmonization for Heterogeneous Datasets: A Systematic Literature Review

The work describes how increased data size affects its variety. Investigating such diverse data sets is one of the most difficult tasks in information management and data analysis. Data heterogeneity and decentralization have an impact on data visualization and prediction, which in turn influences analytical results. Data harmonization (DH) is a field that integrates the representation of such various types of data. Several techniques have been developed over the years to reduce the variety and disparity in formats of huge data kinds. This study conducted a comprehensive evaluation of the literature to evaluate the state-of-the-art DH approaches. The purpose of this study was to better understand the challenges presented by heterogeneity, the necessity for DH, and the approaches used to cope with large heterogeneous textual datasets. The procedure generated 1355 papers, however only 70 were determined to be relevant using inclusion and exclusion criteria methods. The results show that the heterogeneity of structured, semi-structured, and unstructured (SSU) data may be managed utilizing DH and its basic approaches, such as text preprocessing, Natural Language Preprocessing (NLP), machine learning (ML), and deep learning (DL). These techniques are used in a wide range of real-world applications, mostly in information retrieval. To test the efficiency of these strategies, several metrics were used, including precision, recall, F-1, accuracy, and time. A

thorough explanation of each research question, typical methodology, and performance measures is provided. Finally, we provide readers with a full assessment of the current work, contributions, and managerial and academic consequences, as well as the conclusion, limitations, and future research objectives [26].

REDCap on FHIR: Clinical Data Interoperability Services

This paper discusses the development of the REDCap Clinical Data Interoperability Services (CDIS) module, which facilitates seamless data sharing between the REDCap research electronic data capture (EDC) system and any EHR system that supports an FHIR API. CDIS empowers end users to independently set up data collection projects, map EHR data to specific fields, and manage data transfers without requiring the involvement of Health Information Technology specialists for each project.

Methods: We identified two scenarios for transferring EHR data into REDCap. The Clinical Data Pull (CDP) automatically imports EHR data into user-defined REDCap fields, eliminating the need for manual transcription or copying and pasting from the EHR. The Clinical Data Mart (CDM) gathers all necessary patient data over a specified period, streamlining the process of importing EHR data for registries from research databases. We used an iterative approach to develop access control, authentication, variable selection, and mapping interfaces, enabling end users to quickly set up and utilize CDIS. Since its launch, the REDCap CDIS has been used to collect over 19.5 million data points for 82 projects at Vanderbilt University Medical Center. The REDCap Consortium provides the necessary software and documentation.

Conclusions: The new REDCap Clinical Data Interoperability Services (CDIS) module leverages the FHIR standard for real-time, direct data extraction from the EHR. Researchers can independently map and manage EHR data within REDCap. The implementation of CDIS at VUMC and other REDCap consortium sites enhances the accuracy and efficiency of EHR data collection by eliminating the need for manual data transcription and flat file uploads [27].

Development of a Generalizable Multi-site and Multi-Modality Clinical Data Cloud Infrastructure for Pediatric Patient Care

This study creates and executes a safe and interoperable data harmonization system to improve data value across several clinical sites and data types. A FHIR-enabled data repository is produced by converting current multi-modal clinical data in various formats into standardized FHIR resources. The data value is further increased by giving clinical users easy and secure access via user-friendly application interfaces. The data access and standardization solution enable healthcare professionals to swiftly upload existing data, query individual patient data, and retrieve curated patient groups to optimize clinical research recruitment. Finally, three unique real-world clinical case studies are used to demonstrate the technology architecture's universal applicability. This work is valuable because it offers a solution for major worldwide healthcare systems to generate value and clinical insights from their data across clinical domains, with the ultimate goal of improving pediatric patient care [28].

A Novel Approach for Clinical Data Harmonization

This paper explores how a city can transform into a "smart" city by leveraging data from smart devices, cloud infrastructures, applications, and repositories to create and offer new services, products, and insights aimed at fostering a safer, more efficient, and resilient environment for governments, citizens, and businesses, while also promoting sustainable economic growth. While a city's cultural background, demographics, existing infrastructures, and geography may lead to variations in specific smart city objectives, health remains a crucial factor in achieving these broader goals. A key step in integrating health into smart city initiatives involves the intelligent processing of the vast amounts of clinical data continuously generated through healthcare services, daily activities, and clinical research. The significant heterogeneity of clinical data—across system, syntactic, structural, and semantic levels—along with its sensitive legal and ethical considerations, presents major challenges for applying big data analytics to clinical data within a smart city context. This paper introduces a new method for representing clinical data using a unified formalism with clearly defined terminology semantics. This semantic foundation enables queries on health-related data for purposes such as disease prevention, treatment monitoring, post-marketing surveillance, policy-making, and more [29].

New Tools for Data Harmonization and Their Potential Applications in Organ Transplantation

To effectively analyze clinical outcomes in organ transplantation, it is crucial to have access to extensive, high-quality data sets. Various factors, including donor and recipient characteristics, transplant details, and post-transplant events, influence outcomes, which can vary over time. While large data sets exist and continue to grow in transplant registries and healthcare institutions, they are seldom combined for analysis due to a lack of harmonization. With the digitalization of healthcare, effective data harmonization technologies have emerged, offering potential applications in organ transplantation. This paper examines the current challenges in harmonizing organ transplant data and proposes strategies to enhance data accuracy through emerging technological tools. To tackle the issue of inadequate representation of transplant-specific terminology, the development and support of ontologies and common data models tailored to this field by a consortium of relevant stakeholders could ensure broad adoption. Implementing explicit data-sharing policies could reduce administrative barriers to collaboration between organizations. Secure multiparty computation frameworks and the Artificial Intelligence (AI) technique known as federated learning offer the possibility of decentralized, harmonized data analysis without compromising patient privacy or revealing sensitive information. Additionally, a shared imaging data model based on standardized formats would be beneficial for AI-driven pathological image analysis. The adoption of these new tools and methods, ideally with the involvement and backing of transplant societies, is expected to lead to better integration and harmonization of transplant data, resulting in more precise clinical decision-making and improved patient outcomes [30] .

2.7. Overview of Rwanda health facilities

The Figure 2.2 depicts the country's well-functioning, decentralized healthcare public service system, which includes 1700 health posts, 500 health facilities, 42 district hospitals, and 5 national referral hospitals. Rwanda also boasts a thriving private health-care industry, which includes 2 general hospitals, 2 eye hospitals, 50 clinics and polyclinics, 8 dental clinics, 4 eye clinics, and 134 dispensaries. There is one Joint Commission International-certified hospital and one public medical college that graduates 100 general practitioners each year. Rwanda intends to enhance the provision of better healthcare and develop medical tourism by attracting state-of-the-art and specialized medical institutions [31] [32][33] [34][35][36].

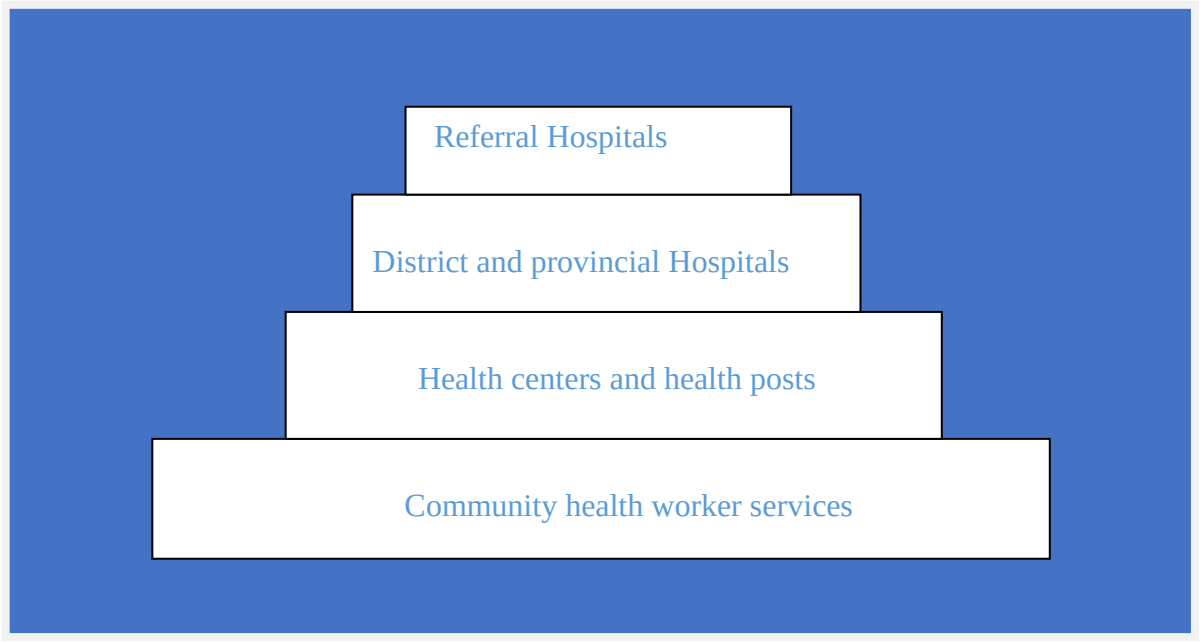

Figure 2. 2. Services provided by the Rwandan health system

CHAPTER 3. RESEARCH METHODOLOGY

In this chapter the methods and approaches used to conduct the study are outlined. This includes the steps undertaken to complete the study, the system design methodology and tools used in data collection, and prototyping of the proposed solution.

3.1 Research Process

The research process consists of a series of systematic procedures that the author passed through to conduct this study from conception to the project realization. The researcher started by identifying the problem faced by Rwandan health system clients related to the service delivery and set the objectives and research questions for addressing the identified problem. Literature is evaluated for consulting other author's work for the purpose of understanding the current state of knowledge, identifying gaps in the literature, and refining author's research questions.

The research is then designed in line with the system requirements and service to be provided, the system need assessment is conducted and gathered data are analyzed and interpreted, the prototype is developed, deployed and tested. The findings are reported and finally the conclusion and recommendations are developed. All these steps are presented in figure 3.1.

Figure 3. 1. Research process [37]

3.2. Materials

A google form and questionnaire are used as data collection tool while the data analysis was conducted with the use of Microsoft excel sheet. The design and prototyping are achieved with the help of different software tools such as HTML to structure the content into headings, paragraphs, lists, and other elements, making it easier to read and navigate and CSS to control the presentation of webpages by determining the layout, colors, fonts, and overall appearance. Mysql for database tools and php, and javascript as programming languages. The system components consist of data ingestion equipment such as a computer for data recording and user interface, data communication channel which is in this case an internet and data storage and management to handle data request by providing accurate and specific requested information.

3.3. Need assessment data collection methods

Quantitative data related to the clinical services such as extra cost due to repetitive tests, tendance of being served with incompatible medicines and diagnostic due to chronical and other illness, are collected with the use of a questionnaire/ google forms shared to sampled patients. In addition to the questionnaire, a review of literature is used to collect secondary data related to the health system structures, operation of existing information system in health sector and its challenges that hinters to share data among different health facilities.

3.3.1. Target population

The targeted population are the patients requesting health services in different types of Rwandan health facilities including private clinics, public health centers, district hospitals, provincial and referral hospitals.

3.3.2. Sample sizes

The questionnaires are distributed among forty-two (42) respondents as follows: 12 from private clinics, 12 from public health centers, 8 from district hospitals, 5 from provincial hospitals and 5 from referral hospitals. The choice of the sample is based on the type of services provided at each level of facility and the number of respondents attending to the services in place. Since the healthcare facilities at different levels are represented in the sampling procedure, with the number aligned with the quantity of the facilities at each level, the information collected is trusted and can

represent the whole country. In addition, the secondary data collected from reviewing literature are complementing with those collected from respondents which emphasizes the author's decision.

3.3.3. Need assessment Data analysis

Nine (9) different questions were set and distribute to 42 respondents from different levels of health facilities to evaluate the quality of the services given within a non-harmonized and shared clinical data. Some questions were given an option to answer with Yes or No and others are set together some specific information for the purpose of improving the accuracy of the gathered information. As presented in the figure 3.2, the answers obtained showed that some healthcare facility use the information system through which patients' data are stored and managed but there is a lack of harmonization between different healthcare facilities so that their services can be improved.

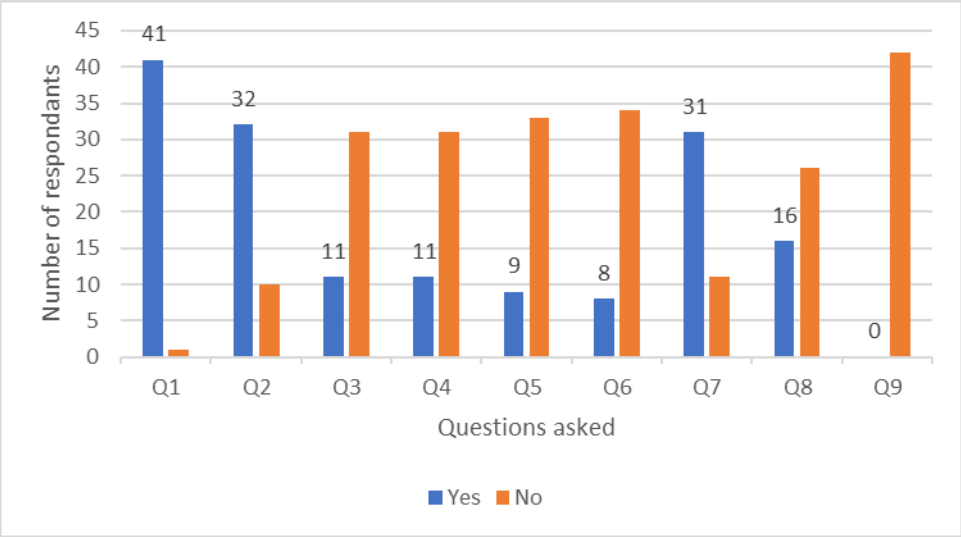

Figure 3. 2. Data Analysis chart

The need assessment showed that 76.2% of the respondents have conducted unwanted repeated tests for similar case at different healthcare facility as presented by question 2, 26.2% of the respondents have given allergic medication, 19% of the respondent have given medications against their chronical diseases, 61.9% of the respondents results are communicated trough paper work and compact discs within the same healthcare facility while 100 % of the results are communicated trough paper work and compact discs in separate healthcare facility.

3.3.4 Ethical Considerations

This research project was approved by the UR/ CMHS IRB Board, and this assured that this research complies with ethical guidelines. The goals of the study and the procedures used to gather the data were explained to the respondents in a clear and simple manner. The technique used to obtain the

data was simple to comprehend and required little time from the participants. Only the information required on the research question was gathered. No personal information was asked. Anonymization was applied to the data.

3.4. SOFTWARE DEVELOPMENT METHODS

The software development models are the various processes or methodologies that are being selected for the development of the project depending on the project's aims and goals. There are many system development life cycle models that have been developed in order to achieve different required objectives.

Various software development models such as V Model, Waterfall, Spiral Model, Incremental Model, Scrum, Kanban, XP, and RUP exists but in this thesis a waterfall method is used since it is suitable to the projects that follow a wide range of regulations and rules, such as healthcare projects.

3.4.1. Waterfall Development Model

The first process model to be introduced was Waterfall Model also known as the linear-sequential life cycle model. It is really easy to learn and utilize. In a waterfall model, each phase must be finished before the next one can begin, and the phases do not overlap. Waterfall model is the earliest SDLC approach that was used for software development.

The waterfall Model depicts the software development process in a linear sequential flow, hence it is also known as a linear-sequence life cycle model. This means that any subsequent phase of the development process can only begin if the prior step is completed. In the waterfall model, phases do not overlap.

3.4.2. Waterfall Model design

The Waterfall technique was the first SDLC model that was widely utilized in Software Engineering to ensure project success. In "The Waterfall" technique, the entire software development process is separated into different phases. In the Waterfall model, normally, the conclusion of one phase works as the input for the following phase consecutively. The figure 3.3 shows a diagrammatic representation of different phases of waterfall model as shown in [38][39][40][41][42][43].

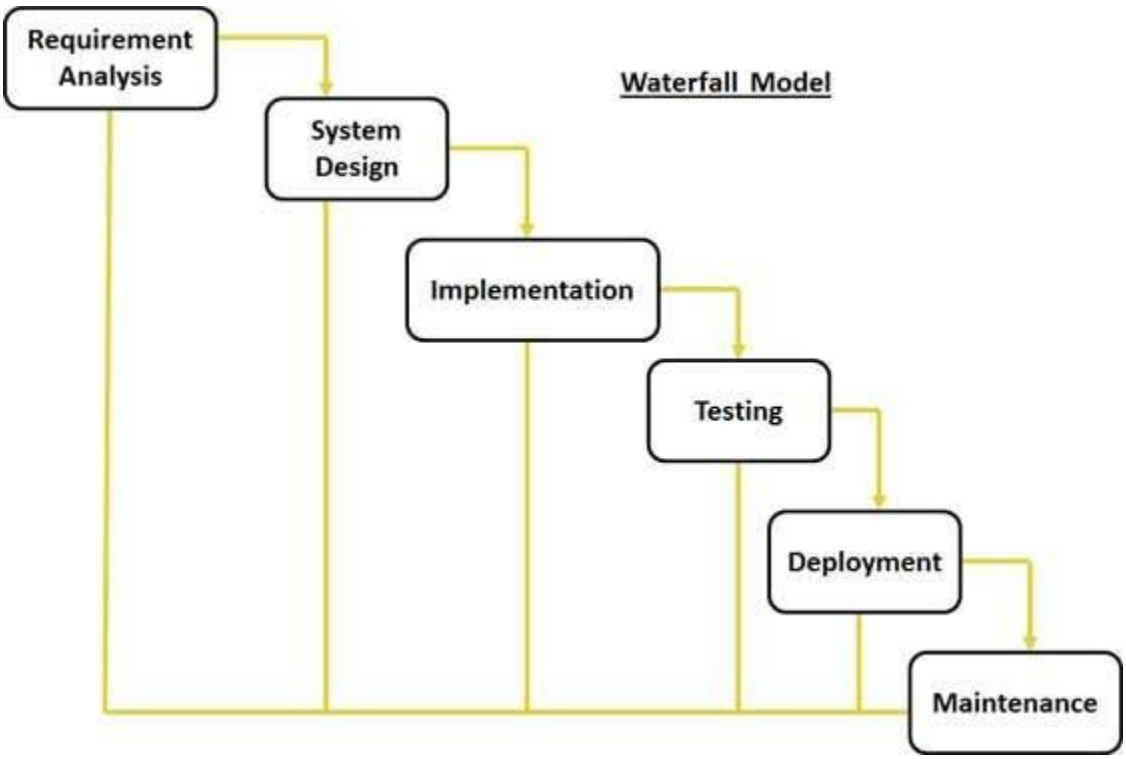

Figure 3. 3. Waterfall model design

All these phases are cascaded to each other in which progress is seen as flowing steadily downwards (like a waterfall) through the phases. The next phase is started only after the defined set of goals are achieved for previous phase and it is signed off, so the name "Waterfall Model". In this model phases do not overlap.

Every software developed is different and requires a suitable SDLC approach to be followed based on the internal and external factors. Some situations where the use of Waterfall model is most appropriate are:

- Requirements are very well documented, clear and fixed.
- Product definition is stable.
- Technology is understood and is not dynamic.
- There are no ambiguous requirements.
- Ample resources with required expertise are available to support the product.
- The project is short[44].

The system requirements such security, interoperability, data management, user Interface and experience, performance and reliability, and data sharing capabilities are analyzed to ensure that that the system can share patient's data securely, efficiently, and in compliance with regulatory standards, ultimately supporting better healthcare outcomes through improved data accessibility and interoperability.

The system was designed through its architectural design in which scalable and modular system are developed, the mapping out of how data will flow through the system from collection to sharing is established, the core components of the system including databases, APIs, user interfaces, and middleware are developed and finally the system is hosted to be accessed at different locations.

3.5. Research design

3.5. 1. Design and prototyping the system

Resulting from the needs assessment of data harmonization system in Rwandan health sector, I started the system development in which the system components required for its effective operation were modelled, simulated, and evaluated in order to ensure interoperable and secure system. The whole system consists of 3 facilities samples where five (5) patients are registered in each facility and their clinical, therapeutic data and laboratory results are communicated through the same system with a single identification number.

3.5.2. Data flow diagrams

A DFD maps out the flow of information for the developed system. It shows the data inputs, outputs, storage points and the routes between each destination. The system consists of two users, administration and doctor user in which information flow should be managed.

To log in in the administration user, the username and password should be entered, the system checks the logging credentials and gives permission to access the staff account and information for registration and management as shown in figure 3.4.

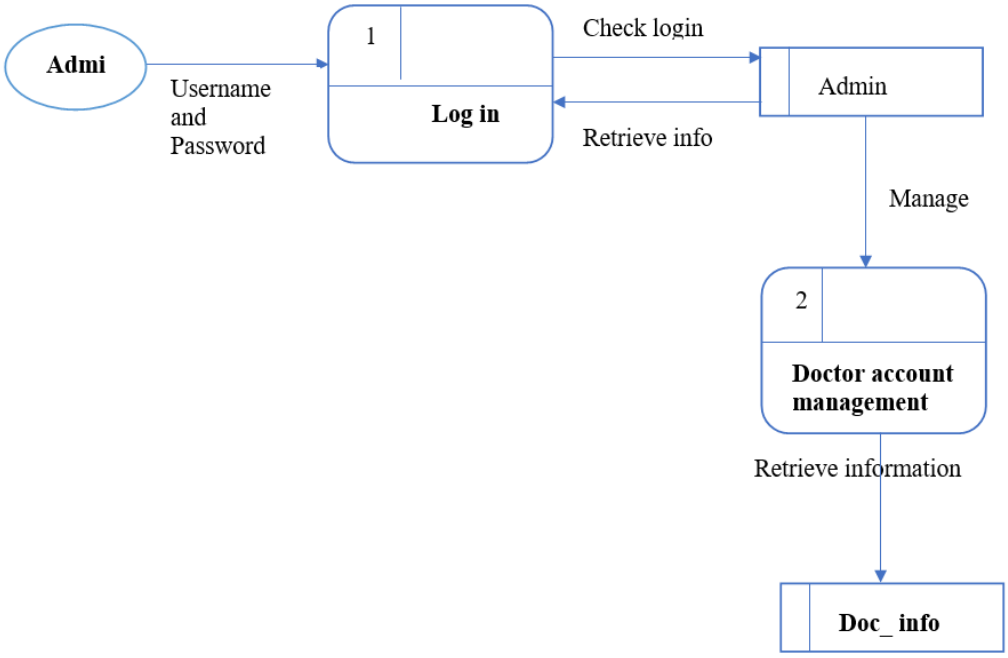

Figure 3. 4. Administrator directory data flow [45][46]

Once the doctor's user account is created, the user can log in by using his/her credentials and can access his account for patients' registration, management, viewing medical records and information, recommending laboratory tests and receiving laboratory results.

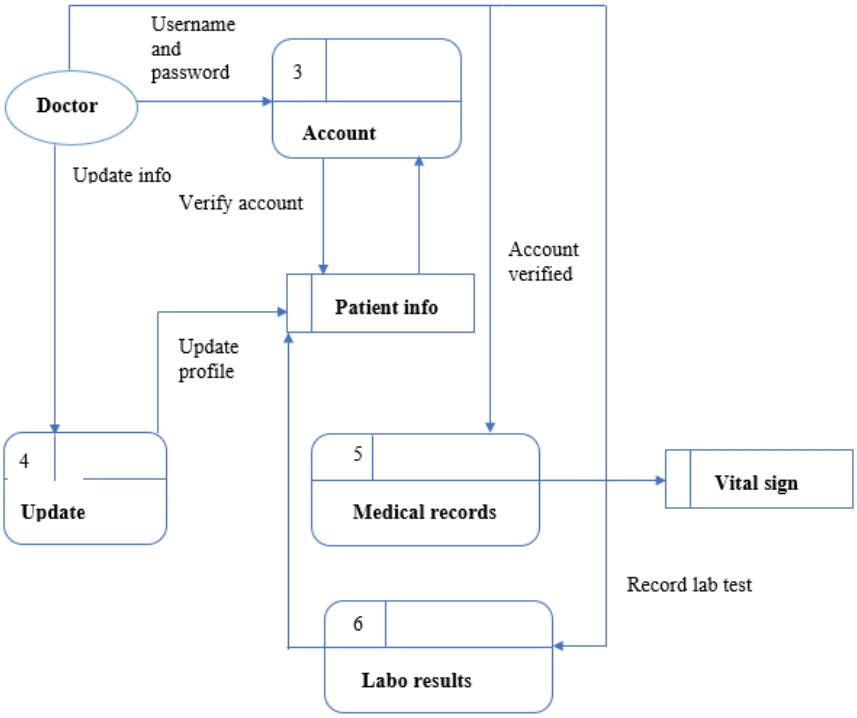

Figure 3. 5. Doctor directory data flow [45][46]

3.5.3. System block diagram

The system components consist of data ingestion equipment such as a computer or a smart phone for data recording and user interface, data communication channel which is in this case an internet and data storage and management to handle data request by providing accurate and specific requested information. The block diagram for the system is shown in figure 3.6.

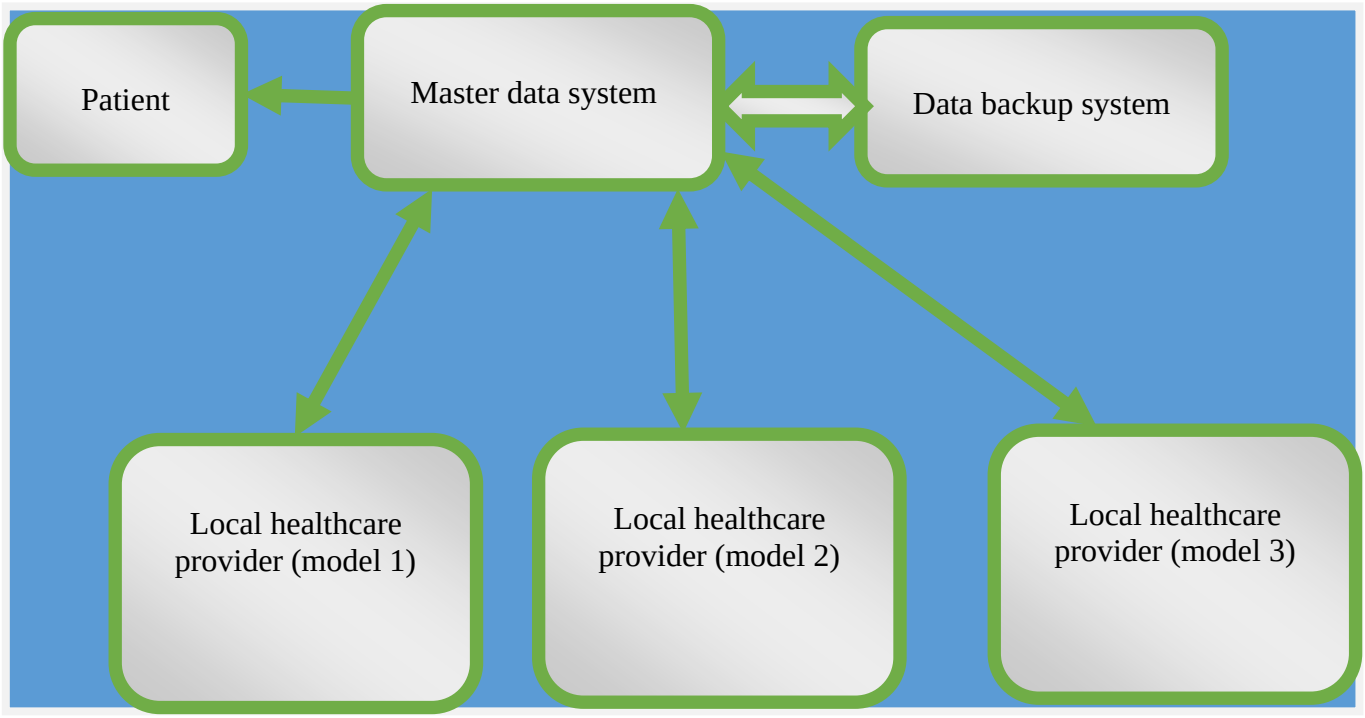

Figure 3. 6. System block diagram

3.5.4. Physical data model

A physical data model specifies how the data model will be built in the database. It outlines all table structures, including column name, data types, column constraints, primary key and foreign key with indexes to the relevant table column, relationships between tables, stored procedures, and views. The Database tables as the fundamental structure within a relational database management system that stores and organizes data in this system have been created and are presented in figures from 3.7 to 3.17. Each table represents a specific entity, such as admin, patients, doctors and different services:

	#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
☐	1	**ad_id** 🔑	int(20)			No	*None*		AUTO_INCREMENT	Change Drop More
☐	2	**ad_fname**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	3	**ad_lname**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	4	**ad_email**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	5	**ad_pwd**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	6	**ad_dpic**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More

Figure 3. 7. Admin Table

	#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
☐	1	**doc_id** 🔑	int(20)			No	*None*		AUTO_INCREMENT	Change Drop More
☐	2	**doc_fname**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	3	**doc_lname**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	4	**doc_email**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	5	**doc_pwd**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	6	**doc_dept**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	7	**doc_number**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	8	**doc_dpic**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More

Figure 3. 8. Doctor table

	#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
☐	1	**lab_id** 🔑	int(20)			No	*None*		AUTO_INCREMENT	Change Drop More
☐	2	**lab_pat_name**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	3	**lab_pat_ailment**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	4	**lab_pat_number**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	5	**lab_pat_tests**	longtext	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	6	**lab_pat_results**	longtext	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	7	**lab_number**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	8	**lab_date_rec**	timestamp			Yes	current_timestamp()		ON UPDATE CURRENT_TIMESTAMP()	Change Drop More

Figure 3. 9. Laboratory table

#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
1	mdr_id	int(20)			No	None		AUTO_INCREMENT	Change Drop More
2	mdr_number	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
3	mdr_pat_name	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
4	mdr_pat_adr	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
5	mdr_pat_age	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
6	mdr_pat_ailment	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
7	mdr_pat_number	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
8	mdr_pat_prescr	longtext	latin1_swedish_ci		Yes	NULL			Change Drop More
9	mdr_date_rec	timestamp(4)			No	current_timestamp(4)		ON UPDATE CURRENT_TIMESTAMP(4)	Change Drop More

Figure 3. 10. Medical_records

#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
1	pat_id	int(20)			No	None		AUTO_INCREMENT	Change Drop More
2	pat_service_id	bigint(20)		UNSIGNED	Yes	NULL			Change Drop More
3	pat_fname	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
4	pat_lname	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
5	pat_dob	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
6	pat_age	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
7	pat_number	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
8	pat_addr	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
9	pat_phone	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More

Figure 3. 11. Patient table

#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
1	t_id	int(20)			No	None		AUTO_INCREMENT	Change Drop More
2	t_hospital	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
3	t_date	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
4	t_pat_name	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
5	t_pat_number	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More
6	t_status	varchar(200)	latin1_swedish_ci		Yes	NULL			Change Drop More

Figure 3. 12. Patient_transfers

	#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
☐	1	**phar_id** 🔑	int(20)			No	*None*		AUTO_INCREMENT	Change Drop More
☐	2	**phar_name**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	3	**phar_bcode**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	4	**phar_desc**	longtext	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	5	**phar_qty**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	6	**phar_cat**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	7	**phar_vendor**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More

Figure 3. 13. Pharmaceutals table

	#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
☐	1	**pharm_cat_id** 🔑	int(20)			No	*None*		AUTO_INCREMENT	Change Drop More
☐	2	**pharm_cat_name**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	3	**pharm_cat_vendor**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	4	**pharm_cat_desc**	longtext	latin1_swedish_ci		Yes	*NULL*			Change Drop More

Figure 3. 14. Pharmaceutals_categories

	#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
☐	1	**pres_id** 🔑	int(200)			No	*None*		AUTO_INCREMENT	Change Drop More
☐	2	**pres_pat_name**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	3	**pres_pat_age**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	4	**pres_pat_number**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	5	**pres_number**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	6	**pres_pat_addr**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	7	**pres_pat_type**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	8	**pres_date**	timestamp(4)			No	current_timestamp(4)		ON UPDATE CURRENT_TIMESTAMP(4)	Change Drop More
☐	9	**pres_pat_ailment**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	10	**pres_ins**	longtext	latin1_swedish_ci		Yes	*NULL*			Change Drop More

Figure 3. 15. Prescriptions table

	#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
☐	1	**id** 🔑	bigint(20)		UNSIGNED	No	*None*		AUTO_INCREMENT	Change Drop More
☐	2	**name**	varchar(255)	utf8mb4_general_ci		No	*None*			Change Drop More
☐	3	**code**	varchar(255)	utf8mb4_general_ci		No	*None*			Change Drop More

Figure 3. 16. Hospital_services

	#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
☐	1	**vit_id** 🔑	int(20)			No	*None*		AUTO_INCREMENT	Change Drop More
☐	2	**vit_number**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	3	**vit_pat_number**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	4	**vit_bodytemp**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	5	**vit_heartpulse**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	6	**vit_resprate**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	7	**vit_bloodpress**	varchar(200)	latin1_swedish_ci		Yes	*NULL*			Change Drop More
☐	8	**vit_daterec**	timestamp(6)			No	current_timestamp(6)		ON UPDATE CURRENT_TIMESTAMP(6)	Change Drop More

Figure 3. 17. his_vitals

3.5.5. Prototype testing

The developed clinical data harmonization system is tested by registering five (5) patients on each among three (3) developed healthcare providers' systems and their data are recorded, shared and published though the master data system through which the patients' data from any care provider are fetched and used prior to the next service. The results are presented and discussed in chapter four.

CHAPTER 4. RESULTS AND DISCUSSION

This chapter represents the results of the developed system wherein the prototype consists of four subsystems, the master and the three models of local healthcare services providers which are synchronized together in the master system.

4.1 The system welcome page

The overall system comprises of three systems in which users (admin and doctors) can login and perform the required tasks in line with their privileges as shown in figures 4.1.

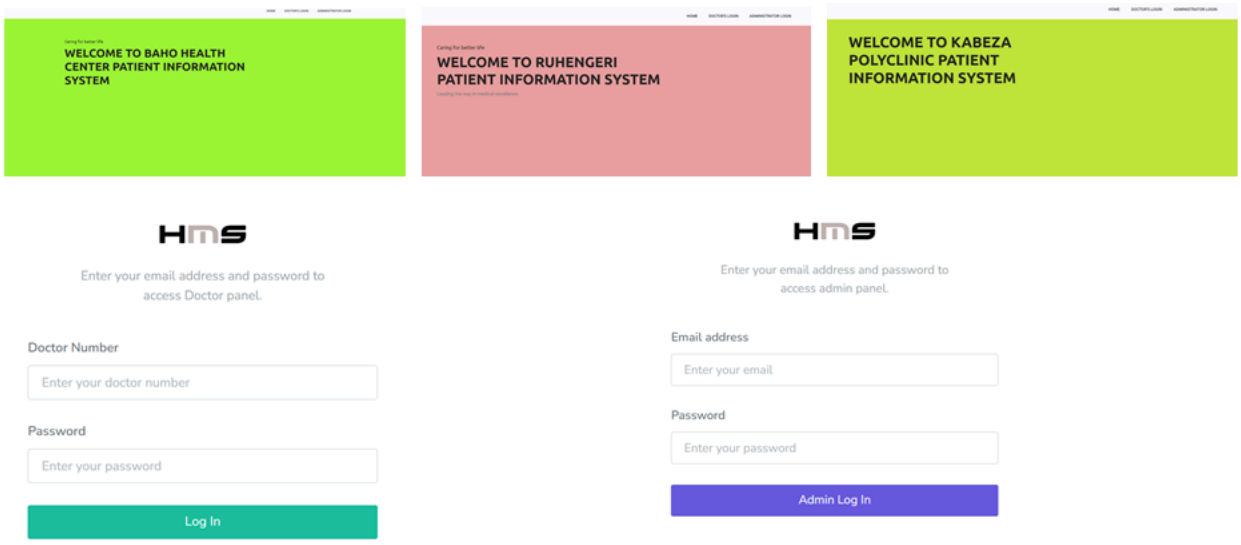

Figure 4. 1. Login page

The system is designed in such a way that to access the user panel, the user has to input his own credentials for the system to recognize that the user is fully qualified and allowed to enter the system and perform his jobs in a professional manner. The system designer registers the administrators, while system administrators register the doctors or medical staff in the system.

4.2 Healthcare provider information system navigation page

The navigation page shows different directories, such as patients, pharmacy, inventory, laboratory, and dashboard. The dashboard represents the user profile and the recent services rendered in terms of type of service and the number of patients served for each service for the purpose of simplifying the overall report required for each service. The sample of Baho Hospital is shown in Figure 4.2. The page displays all recently provided services, detailing the number of clients served for each service hence providing a quick report on alarming issues.

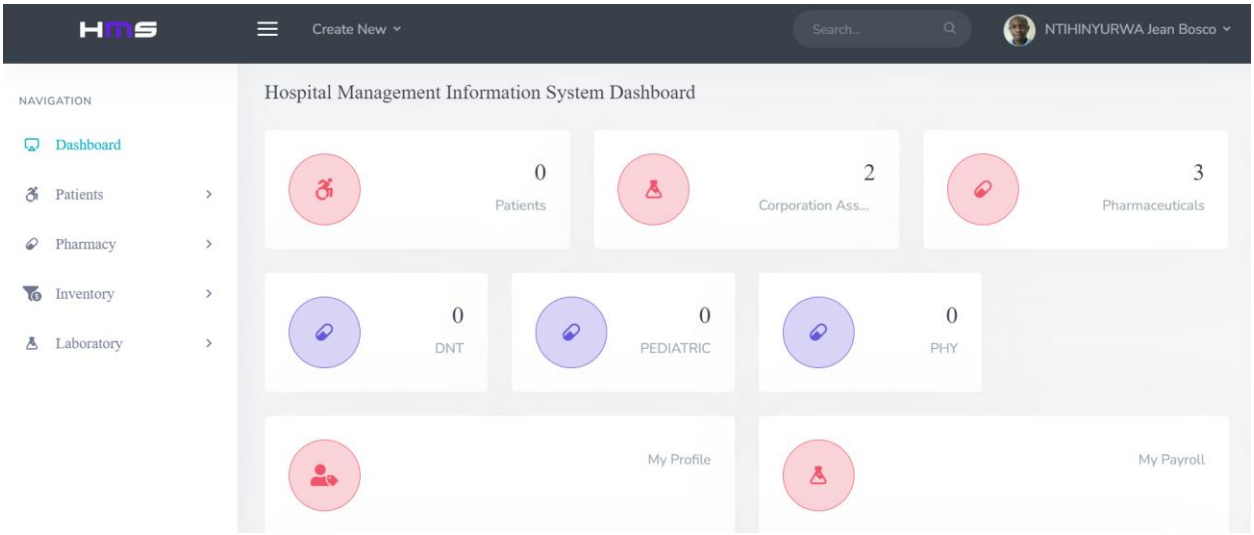

Figure 4. 2. Information system navigation page and dashboard

4.3 Patient directory

In line with the patient's clinical service requirements, this directory is designed to consist of five (5) entries, including register patients where a new patient can be added or an existing patient can search, view patients where patients 'past clinical history can be viewed and interpreted, manage patients in which the patient data can be updated, and patient transfer in which the patient can be transferred to a higher-profile healthcare provider, as shown in figure 4.3. To secure the patient's data from being seen by an unauthorized healthcare provider, the patient is given a code that is generated during the patient's registration and kept by the patient for future use. In case the code is lost, only the admin and patient's doctor have the privilege to restore the patient's account, but this can be simplified through communication between the institution in which he is requesting the service and where he has been registered.

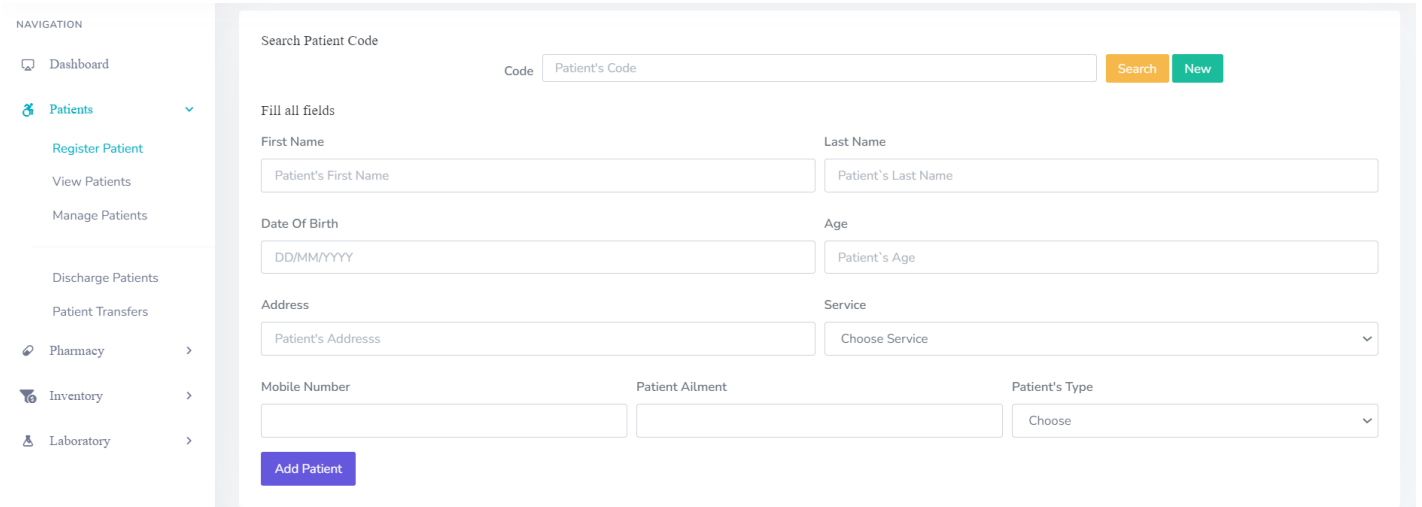

Figure 4. 3. Patient director

If the patient is already registered, he does not need to be registered again; instead, his code is typed and searched to access the previous medical history. The registered patients of each healthcare provider with their identification are shown in tables 4.1, 4.2, and 4.3. The table also shows the action on one hand for viewing the patient profile and existing data as well as entering new records, and on the other hand for managing and updating existing data.

Table 4. 1. Baho health center attended patients

Search

#	Patient Name	Patient Number	Patient Address	Patient Phone	Patient Age	Patient Category	Action
1	UWIMANA Sandrine - oZRJF	MAO6K	Kibungo	0788888890	25 Years	InPatient	View
2	Shimwa Annet - clj6a	UN7QE	Nyakabanda	0790225501	14 Years	InPatient	View
3	UWIMANA Assoumani - ofXqN	C8102	Gatobo	0788691750	40 Years	InPatient	View
4	MAHORO Cynthia - 5zUNZ	R2EIL	Karongi	0781122334	24 Years	OutPatient	View
5	UWERA Louise - GYKp7	NCDTJ	Nyagasenyi	0791543229	25 Years	OutPatient	View
6	NTAGANZWA Jean Paul - FNiH8	IT63F	KARONGI	0791521120	24 Years	InPatient	View

« ‹ 1 › »

Table 4. 2. RUHENGERI attended patients

Search

#	Patient Name	Patient Number	Patient Address	Patient Phone	Patient Age	Patient Category	Action
1	NTAGANZWA Jean Paul - FNiH8	IT63F	KARONGI	0791521120	24 Years	InPatient	View
2	IRAKIZA Gaga Sonia - TVacP	H90R6	Muhanga	0788888890	25 Years	InPatient	View
3	KAMBANDA Samuel - Fly3Z	DE0BN	Mahoko	0788691750	1 Years	InPatient	View
4	MAHORO Cynthia - 5zUNZ	R2EIL	Karongi	0781122334	24 Years	OutPatient	View
5	INEZA APHONSINE - Dx5wP	LVI3Y	Kayonza	0791543229	21 Years	InPatient	View

« ‹ 1 › »

Table 4. 3. KABEZA Polyclinic attended patients

Search

#	Patient Name	Patient Number	Patient Address	Patient Phone	Patient Age	Patient Category	Action
1	NDAYISENGA Venuste - YWv3a	RSQKJ	Nyaruguru	0788888890	75 Years	OutPatient	View
2	NTAGANZWA Jean Paul - FNiH8	IT63F	KARONGI	0791521120	24 Years	InPatient	View
3	NYIRANSENGIMANA Jacqueline - 9Q6pn	G0QD1	RWAMAGANA	0785455162	25 Years	OutPatient	View
4	UWIMANA Sandrine - oZRJF	MAO6K	Kibungo	0788888890	25 Years	InPatient	View
5	HITIMANA Sefu - Qfj3L	OXMSK	Gatizo	0792121445	26 Years	OutPatient	View

4.4 Pharmacy directory

It is reserved for checking and managing available medications, adding a new medication for the purposes of administering a medication that is available, or advising the patient where he can find the administered medications if they are not available at the current hospital. It is under this directory that the prescriptions are assigned to the patient, as shown in figure 4.4. The prescription will be assigned by taking into account the previous medications, previous medical records and current observation and analysis to reduce medical errors.

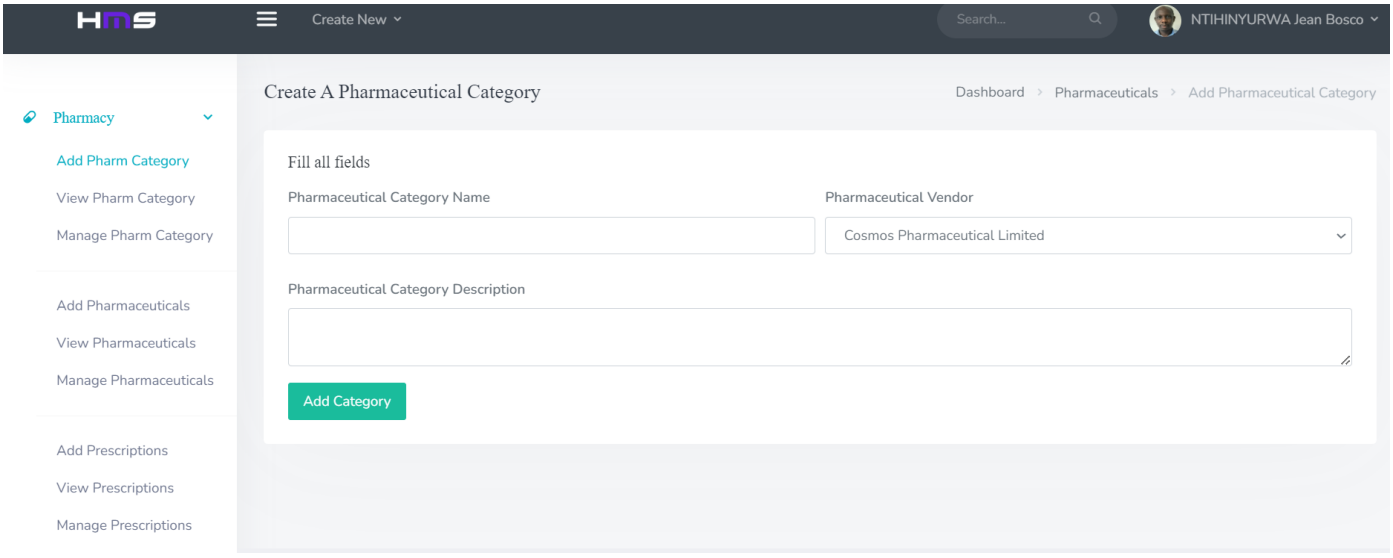

Figure 4. 4. Pharmacy directory

4.5 Laboratory directory

It is reserved for administering laboratory tests, checking laboratory vital signs and results, and viewing laboratory test reports as presented in figure 4.5. The laboratory manager or staff is given the privilege of viewing the administered laboratory test for a specific patient and uploading laboratory results and reports whenever needed. This reduces the negative impacts of carrying the laboratory reports as paper work or on a compact disc.

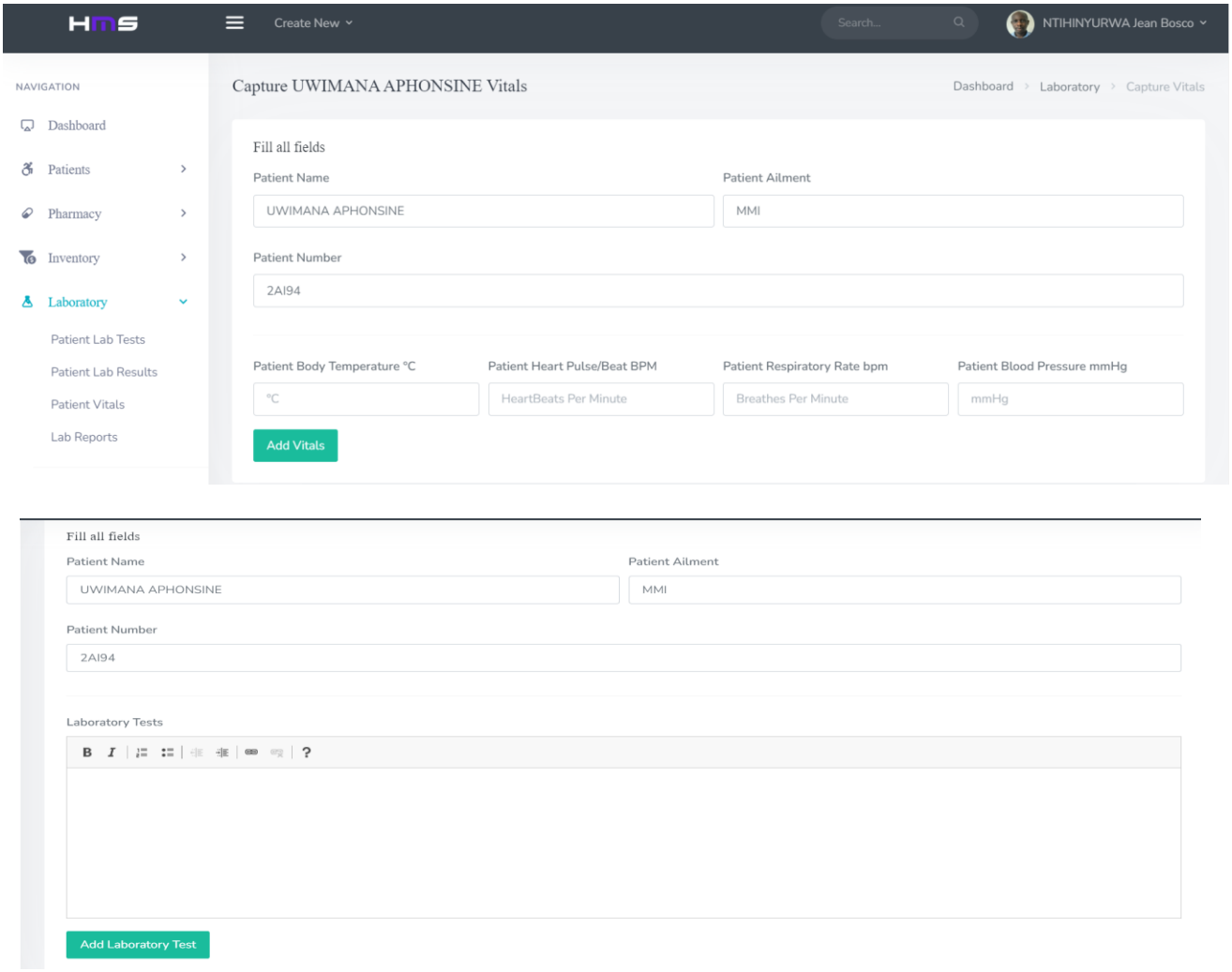

Figure 4. 5. Laboratory directory

4.6. System hosting

The patient data to be shared and viewed from different locations, in-house data recording, and management system need to be hosted to ensure communication among different healthcare facilities. The patients' clinical data is normally their privacy, which is why the author chose the type

of server hosting and the hosting company based on factors such as performance, flexibility, scalability, security, data privacy, and compliance, among others.

4.7. Discussions

The three in-house data recording and management systems are designed and developed through each, and the staff accounts (doctor, laboratory engineer, etc.) are created and used to register the patient requesting the service. The patient registration page is shown in Figure 4.6. If the patient is already registered at any healthcare facility, he or she has to provide his or her code for retrieving his data through the harmonized system; otherwise, the staff has to process the new registration.

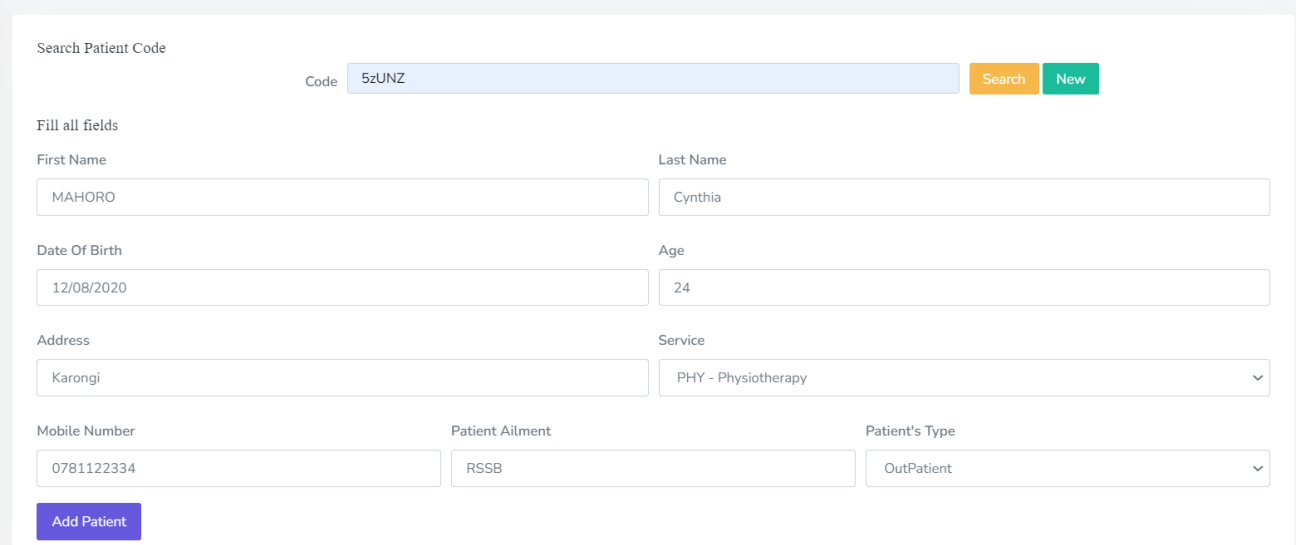

Figure 4. 6. View patients screen

For the new registered patient, the medical processes start directly after registration because there is no medical historian to consult before. But in the case of already existing patients, the medical staff should first check for the past patient's history for proper treatment and diagnostic error reduction. This is achieved by passing through the patient to check his or her past prescriptions, vital signs, laboratory tests, and results, as shown in figures 4.7, 4.8, and 4.9, respectively.

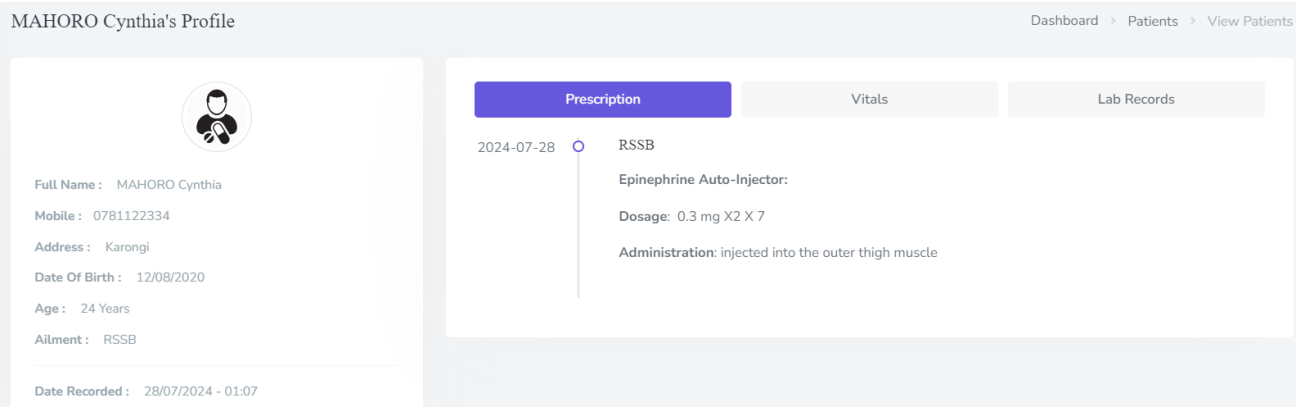

Figure 4. 7. Shared screen for prescription

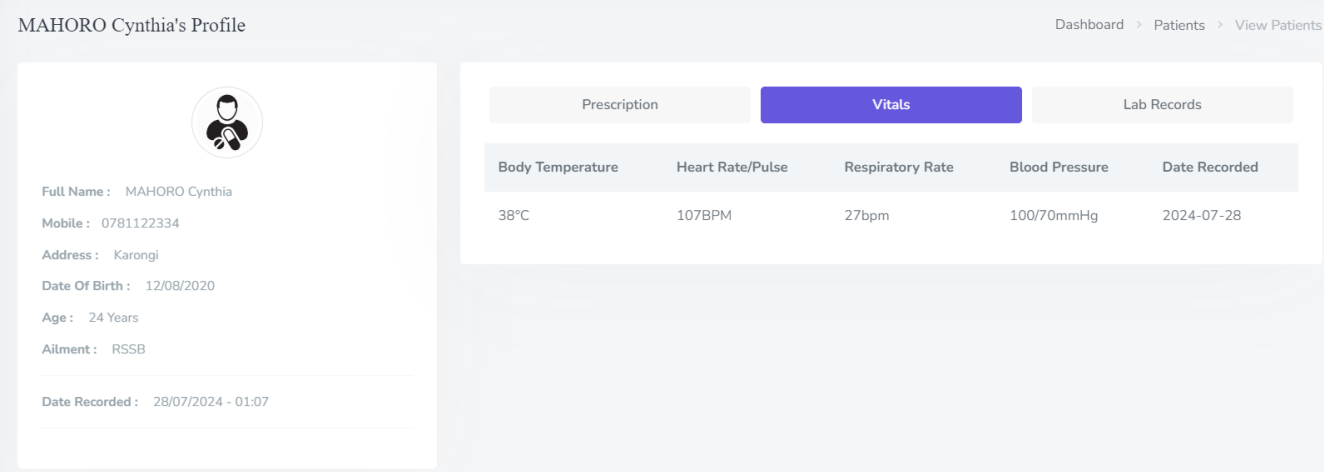

Figure 4. 8. Shared Vital sign data

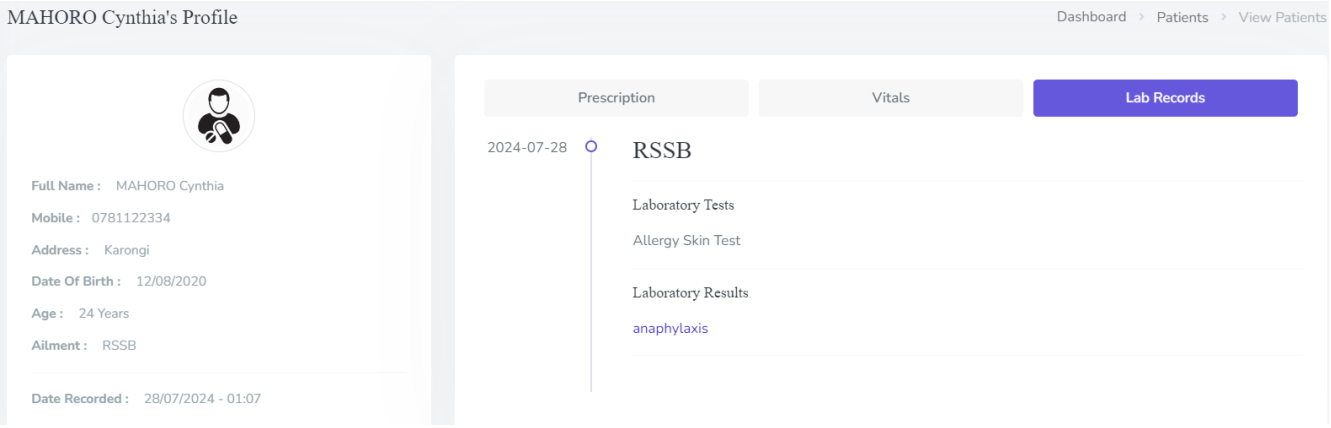

Figure 4. 9. Laboratory records

As presented in figure 4.10, more details for the lab records can be seen by clicking on the highlighted lab results, so that in case it is needed, the medical staff, in charge of the in-coming patient from another facility, can visualize and interpret the uploaded medical test results before

deciding to conduct a similar test. This information enables information decision-making-making making, reduces time wastage and cost due to unwanted repetitive tests, hence improving the efficiency of the patients' clinical services in comparison to the in-house data recording and management system or paper-based clinical services.

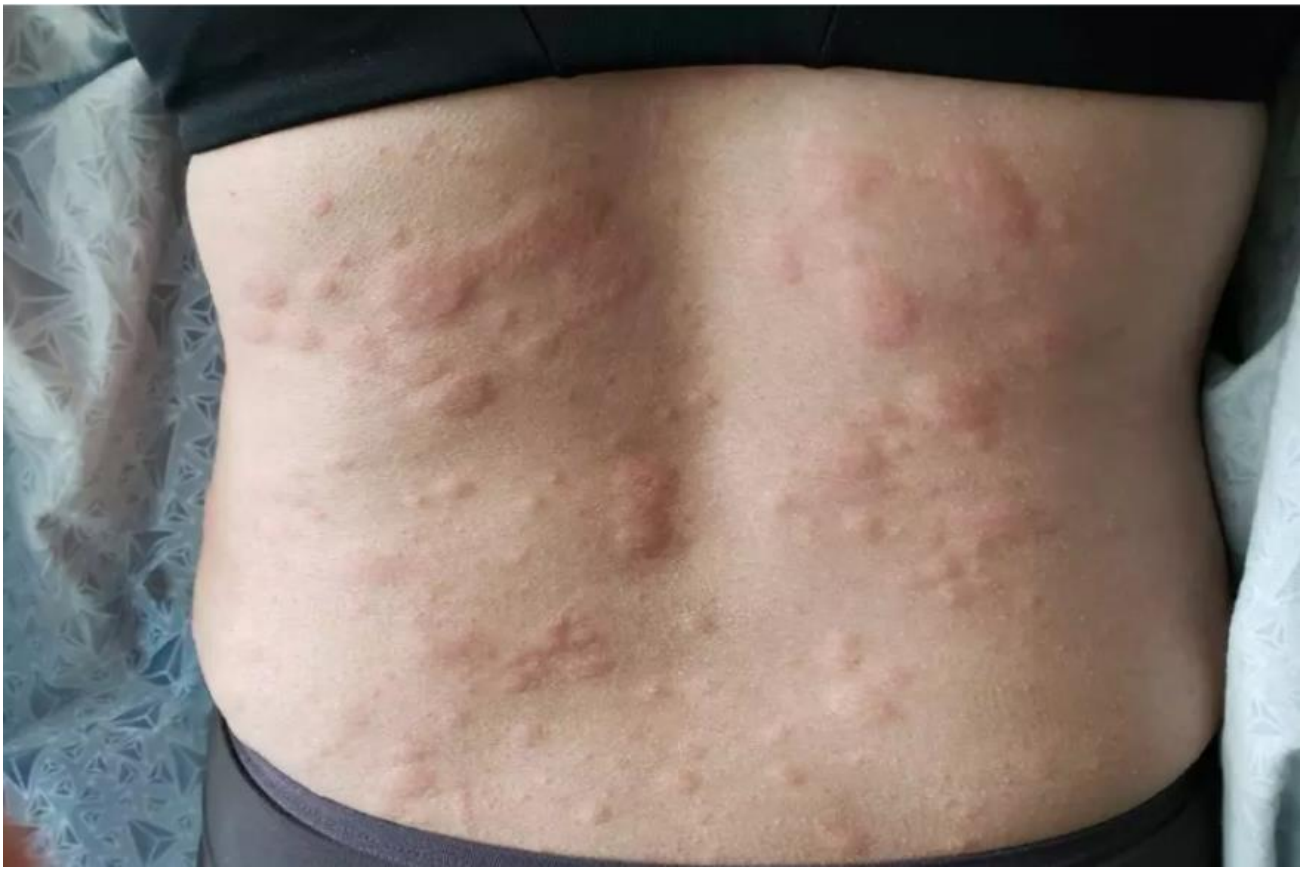

Figure 4. 10. Allergy skin test result_Anaphylaxis

CHAPTER 5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Implementing a data harmonization system in healthcare settings holds immense potential to improve patient care, advance medical research, and enhance public health outcomes. Apart from sharing real-time patients' data, the developed system helps to provide a quick report compared to the existing systems since the reports in the current systems are elaborated on a on a weekly, two-week basis, monthly, or even quarterly basis, depending on the delicacy of the issue to be reported. The author's objectives have been achieved since the developed system is able to record data, manage data, exchange data inside and outside the healthcare facility, and report alarming issues in clinical services. The system is designed, developed, and tested, and it is fully functioning, wherein the data are recorded, stored, and shared among three model systems and can be viewed and updated on each side of the model.

5.2 Recommendations

The author recommends the following:

- Adequate investment in robust IT infrastructure is essential to support the storage, transmission, and analysis of large volumes of healthcare data. The healthcare institutions should invest more in IT infrastructure including upgrading existing systems, implementing secure data storage solutions, and leveraging cloud-based technologies for scalability and flexibility.
- The system users should be trained to enable them use the new technology to ensure informed decision making.
- In some rural areas there is a lack of electricity and intermitted power outages which may hinders the use of digital information system, a standby generator may be availed and the use of renewable energy resources such as solar energy can help to mitigate this problem.
- Future researchers should develop a tool for continuous monitoring and evaluation of the impact of the data harmonization system to identify areas for improvement and ensure that it achieves its intended goals.

REFERENCES

[1] S. Bharadia, "ePRO and Ensuring Data Integrity: Push for accurate data collection during pandemic led by increased focus on patient engagement," *Appl. Clin. Trials*, vol. 30, no. 3, p. 23, 2021.

[2] C. Cheng *et al.*, "A General Primer for Data Harmonization," *Sci. Data*, vol. 11, no. 1, pp. 1–14, 2024, doi: 10.1038/s41597-024-02956-3.

[3] "DATA GOVERNANCE IN HEALTHCARE INFORMATION SYSTEMS : Thesis submitted in fulfillment of the requirements for the degree Master of Technology in Information Technology in the Faculty of Informatics and Design".

[4] *Steve Olson and Autumn S . Downey , Rapporteurs Forum on Drug Discovery , Development , and Translation Forum on Neuroscience and Nervous System Disorders National Cancer Policy Forum Roundtable on Translating Genomic-Based Research for Health Board on He*.

[5] B. Schmidt, C. J. Colvin, A. Hohlfeld, and N. Leon, "Definitions , components and processes of data harmonisation in healthcare : a scoping review," vol. 7, pp. 1–19, 2020.

[6] C. S. Program, "Updating Rwanda ' s Health Management Information System (HMIS) Measuring What Matte rs," no. August, pp. 1–9, 2019.

[7] USAID, "The rwandan health management information system:," no. April 2008, p. 5, 2009.

[8] H. Fraser, M. May, and R. Wanchoo, "E-health Rwanda case study," *Minist. Helalth Rwanda*, no. 15, pp. 5–46, 2008.

[9] R. Chanda, "Draft Evidence Brief No . 7 Regional Harmonization Processes of Health Professional Regulation : Status , Challenges , and Policy Directions Global Code of Practice on the International Recruitment of Health," no. 7.

[10] A. Watt and N. Eng, "Database Design - 2nd Edition," *Creat. Commons Attrib. 4.0 Int. Licens.*, pp. 1–8, 2022, [Online]. Available: http://open.bccampus.ca

[11] A. Steimel, *Electric Traction - Motive Power and Energy Supply*. 2008. [Online]. Available: www.oldenbourg-industrieverlag.de

[12] C. Folden, M. Manke, and T. Mortensen, "Sharing Data : Where To Start Written and edited by," 2007.

[13] A. Woolf, S. J. D. Cox, and C. Portele, "Data Harmonization," *GIGAS reports*, vol. 2, 2010.

[14] Sangwon Lim, "Introduction to Data Harmonization and Modelling Data Harmonization and Modeling : Where does it fit in SW implementation ?," no. April, 2017.

[15] UNESCAP, "Data Harmonization and Modelling Guide for Single Window Environment," *United Nations*, p. 76, 2012, [Online]. Available: https://www.unescap.org/resources/data-harmonization-and-modelling-guide-single-windows-environment

[16] A. Azaria, A. Ekblaw, T. Vieira, and A. Lippman, "MedRec: Using blockchain for medical data access and permission management," *Proc. - 2016 2nd Int. Conf. Open Big Data, OBD 2016*, pp. 25–30, 2016, doi: 10.1109/OBD.2016.11.

[17] R. Garlapati and R. Biswas, "Interoperability in Healthcare - A focus on the Social Interoperability," no. December, p. 71, 2011, [Online]. Available: https://www.diva-portal.org/smash/get/diva2:832850/FULLTEXT01.pdf

[18] C. D. Haule and M. I. Muhanga, "Influence of Health Information Systems on Services Delivery in Public and Private Health Facilities: A Systematic Literature Review," *sub Sahar. J. Soc. Sci. Humanit.*, vol. 09, no. 03, pp. 33–48, 2021, [Online]. Available: https://www.scirp.org/journal/doi.aspx?doi=10.4236/etsn.2020.93003

[19] G. Jiang *et al.*, "Harmonization of detailed clinical models with clinical study data standards," *Int. Conf. Inf. Knowl. Manag. Proc.*, pp. 23–30, 2012, doi: 10.1145/2389672.2389678.

[20] W. Benson, "A Model for improving interoperability of healthcare systems in a distributed environment," pp. 1–86, 2017, [Online]. Available: http://su-

plus.strathmore.edu/handle/11071/5627
[21] C. Std-, “C l i n i c a l D a t a A c q u i s i t i o n S t a n d a r d s H a r m o n i z a t i o n (C D A S H) P r e p a r e d b y :,” 2008.
[22] A. Torres-Espín and A. R. Ferguson, “Harmonization-Information Trade-Offs for Sharing Individual Participant Data in Biomedicine,” *Harvard Data Sci. Rev.*, 2022, doi: 10.1162/99608f92.a9717b34.
[23] E. Williams *et al.*, “FHIR-DHP: A Standardized Clinical Data Harmonisation Pipeline for scalable AI application deployment (Preprint),” *JMIR Med. Informatics*, vol. 11, pp. 1–11, 2022, doi: 10.2196/43847.
[24] O. Spjuth *et al.*, “Harmonising and linking biomedical and clinical data across disparate data archives to enable integrative cross-biobank research,” *Eur. J. Hum. Genet.*, vol. 24, no. 4, pp. 521–528, 2016, doi: 10.1038/ejhg.2015.165.
[25] H. A. Okemiri, A. U. Rita, A. I. Isaiah, O. K. Christian, N. C. Christopher, and C. I. Chima, “Patient data integration: A panacea for effective healthcare,” *J. Comput. Sci.*, vol. 16, no. 2, pp. 235–248, 2020, doi: 10.3844/JCSSP.2020.235.248.
[26] G. Kumar, S. Basri, A. A. Imam, S. A. Khowaja, L. F. Capretz, and A. O. Balogun, “Data harmonization for heterogeneous datasets: A systematic literature review,” *Appl. Sci.*, vol. 11, no. 17, 2021, doi: 10.3390/app11178275.
[27] A. C. Cheng *et al.*, “REDCap on FHIR: Clinical Data Interoperability Services,” *J. Biomed. Inform.*, vol. 121, no. July, p. 103871, 2021, doi: 10.1016/j.jbi.2021.103871.
[28] A. Hornback *et al.*, “Development of a generalizable multi-site and multi-modality clinical data cloud infrastructure for pediatric patient care,” *Proc. 13th ACM Int. Conf. Bioinformatics, Comput. Biol. Heal. Informatics, BCB 2022*, 2022, doi: 10.1145/3535508.3545565.
[29] E. Chondrogiannis, V. Andronikou, E. Karanastasis, and T. Varvarigou, “A Novel Approach for Clinical Data Harmonization,” *2019 IEEE Int. Conf. Big Data Smart Comput. BigComp 2019 - Proc.*, pp. 1–8, 2019, doi: 10.1109/BIGCOMP.2019.8679239.
[30] S. A. Tabatabaei Hosseini, R. Kazemzadeh, B. J. Foster, E. Arpali, and C. Süsal, “New Tools for Data Harmonization and Their Potential Applications in Organ Transplantation,” *Transplantation*, May 2024, doi: 10.1097/TP.0000000000005048.
[31] National Institute of Statistics of Rwanda, “Rwanda Demographic and Health Survey 2010 Final Report,” *Dhs*, p. 574, 2010, [Online]. Available: http://www.worldventure.com/Missionaries/Missionary-Directory/Missionary/Scheer_Gary_Laurie/Links/Downloads/Scheer_Gary_PL_09_06.pdf
[32] “Health Services - Official Rwanda Development Board (RDB) Website.” Accessed: Mar. 20, 2024. [Online]. Available: https://rdb.rw/investment-opportunities/health-services/
[33] Rwanda Ministry of Health, “Private Health Facilities in Rwanda Health Service Packages,” no. January, p. 124, 2017, [Online]. Available: www.moh.gov.rw
[34] U. Bayisenge, J. Schurer, R. Wong, H. Amuguni, and G. Davey, “Podoconiosis in Rwanda: Knowledge, attitudes and practices among health professionals and environmental officers,” PLoS Neglected Tropical Diseases. [Online]. Available: http://dx.doi.org/10.1371/journal.pntd.0008740
[35] H. B. Africa, “Rwanda’s Health Sector Report,” 2021, [Online]. Available: www.ahb.co.ke/publications
[36] P. C. Drobac *et al.*, “Comprehensive and integrated district health systems strengthening: The Rwanda Population Health Implementation and Training (PHIT) Partnership,” *BMC Health Serv. Res.*, vol. 13, no. SUPPL.2, 2013, doi: 10.1186/1472-6963-13-S2-S5.
[37] “Research Process Steps: What they are + How To Follow | QuestionPro.” Accessed: Jul. 28, 2024. [Online]. Available: https://www.questionpro.com/blog/research-process-steps/
[38] and D. B. Kai Petersen, Claes Wohlin, “The Waterfall Model in Large-Scale Development,”

2015 IEEE Canada Int. Humanit. Technol. Conf. IHTC 2015, pp. 386–400, 2015, doi: 10.1109/IHTC.2015.7238067.
[39] Magora, “Waterfall Software Development”.
[40] U. S. Senarath, “Waterfall methodology, prototyping and agile development,” *Tech. Rep.*, no. June, pp. 1–16, 2021, doi: 10.13140/RG.2.2.17918.72001.
[41] Oriana Eason, “Information Systems Development Methodologies Transitions: An Information Systems Development Methodologies Transitions: An Analysis of Waterfall to Agile Methodology Analysis of Waterfall to Agile Methodology,” *Honor. Theses Capstones*, 2016.
[42] “Waterfall Model - Software Engineering - GeeksforGeeks.” Accessed: May 02, 2024. [Online]. Available: https://www.geeksforgeeks.org/waterfall-model/
[43] “SDLC - Waterfall Model.” Accessed: May 02, 2024. [Online]. Available: https://www.tutorialspoint.com/sdlc/sdlc_waterfall_model.htm
[44] “What is the Waterfall Model in Project Management? | Simplilearn.” Accessed: May 02, 2024. [Online]. Available: https://www.simplilearn.com/tutorials/project-management-tutorial/waterfall-model-in-project-management
[45] Z. Lu and J. Su, “Clinical data management : Current status , challenges , and future directions from industry perspectives,” pp. 93–105, 2010.
[46] Y. Nan *et al.*, “Data harmonisation for information fusion in digital healthcare: A state-of-the-art systematic review, meta-analysis and future research directions,” *Inf. Fusion*, vol. 82, no. October 2021, pp. 99–122, 2022, doi: 10.1016/j.inffus.2022.01.001.

APPENDICES

Appendix 1: Questionnaire used for data collection

Thesis Title: DEVELOPMENT OF A CLINICAL DATA HARMONIZATION SYSTEM TO IMPROVE HEALTH CARE SERVICES

Research Questionnaire for healthcare services customers

The purpose of this questionnaire is to gather preliminary information from healthcare services customers. With this information, a clinical data harmonization system will be developed and it will serve as a tool to improve patients' services through informed decision making.

1. Did you ever attend to more than one healthcare providers?

   YES ☐ No ☐
2. Have you ever been asked to conduct repeated tests for similar case at different healthcare providers?

   YES ☐ No ☐
3. Do you have any allergic medication?

   YES ☐ No ☐
4. Is there any case you've been given allergic medications?

   YES ☐ No ☐
5. Do you have any chronical disease?

   YES ☐ No ☐
6. Did you ever have been given medications against your chronical diseases?

   YES ☐ No ☐
7. How the results on a conducted test are communicated to the concerned officials within the same healthcare facility?

   Through paper work ☐ Through the system ☐ Through compact disk ☐
8. Have you ever been asked to conduct medical tests in different healthcare from the one you are attending for?

   YES ☐ No ☐
9. If yes how the results are communicated from testing healthcare to the one in need?

   Through paper work ☐ Through the system ☐ Through compact disk ☐

Appendix 2: Processed respondents answers

S/N	Question Asked	Number respondents who replied "Yes"	Number respondents who replied "No"	Percentage (%) of those who replied with "Yes"	
Q1	Did you ever attend to more than one healthcare providers?	41	1	97.6	
Q2	Have you ever been asked to conduct repeated tests for similar case at different healthcare providers?	32	10	76.2	
Q3	Do you have any allergic medication?	11	31	26.2	
Q4	Is there any case you've been given allergic medications?	11	31	26.2	
Q5	Do you have any chronical disease?	9	33	21.4	
Q6	Did you ever have given medications against your chronical diseases?	8	34	19	
Q7	Have you ever been asked to conduct medical tests in different healthcare from the one you are attending for?	31	11	73.8	
S/N	**Question Asked**	**No of those who responded with Through paper work (1)**	**No of those who responded with Through the system (2)**	**No of those who responded with Through compact disk (3)**	**% of those who responded with (1) and (3)**
Q8	How the results on a conducted test are communicated to the concerned officials within the same healthcare facility?	25	16	1	61.9
Q9	How the results on a conducted test are communicated to the concerned officials in another healthcare facility?	33	0	9	100

Appendix 3: Ethical clearance

UNIVERSITY of RWANDA

COLLEGE OF MEDICINE AND HEALTH SCIENCES

DIRECTORATE OF RESEARCH & INNOVATION

CMHS INSTITUTIONAL REVIEW BOARD (IRB)

Kigali, 27th/12/2023
Ref: CMHS/IRB/569/2023

NTIHINYURWA Jean Bosco (Ref. No. 220012481)
MSc. Degree Student in Biomedical Engineering
Centre of Excellence in Biomedical Engineering and E-Health (CEBE), CST, UR

Dear NTIHINYURWA Jean Bosco

RE: ETHICAL CLEARANCE

Reference is made to your application for ethical clearance for the study entitled ***"Development of a Clinical Data Harmonization System to Improve Healthcare Services."***

Having reviewed your application and been satisfied with your protocol, your study is hereby granted ethical clearance. The ethical clearance is valid for one year starting from the date it is issued and shall be renewed on request. You will be required to submit the progress report and any major changes made in the proposal during the implementation stage. In addition, at the end, the IRB shall need to be given the final report of your study.

We wish you success in this important study.

Assoc. Prof. Stefan Jansen (PhD)
Acting Chairperson Institutional Review Board,
College of Medicine and Health Sciences, UR

Cc:

- Principal College of Medicine and Health Sciences, UR
- University Director of Research and Postgraduate studies, UR

Email: researchcenter@ur.ac.rw P.O Box 3286 Kigali, Rwanda www.ur.ac.rw

Appendix 4: The Utilized Code

```
-- phpMyAdmin SQL Dump
-- version 5.1.1
-- https://www.phpmyadmin.net/
--
-- Host: localhost
-- Generation Time: Apr 07, 2024 at 11:04 AM
-- Server version: 10.4.21-MariaDB
-- PHP Version: 8.1.2

SET SQL_MODE = "NO_AUTO_VALUE_ON_ZERO";
START TRANSACTION;
SET time_zone = "+00:00";


/*!40101 SET @OLD_CHARACTER_SET_CLIENT=@@CHARACTER_SET_CLIENT */;
/*!40101 SET @OLD_CHARACTER_SET_RESULTS=@@CHARACTER_SET_RESULTS */;
/*!40101 SET @OLD_COLLATION_CONNECTION=@@COLLATION_CONNECTION */;
/*!40101 SET NAMES utf8mb4 */;

--
-- Database: `hmisphp`
--

-- --------------------------------------------------------

--
-- Table structure for table `his_accounts`
--

CREATE TABLE `his_accounts` (
  `acc_id` int(200) NOT NULL,
  `acc_name` varchar(200) DEFAULT NULL,
  `acc_desc` text DEFAULT NULL,
  `acc_type` varchar(200) DEFAULT NULL,
  `acc_number` varchar(200) DEFAULT NULL,
  `acc_amount` varchar(200) DEFAULT NULL
) ENGINE=InnoDB DEFAULT CHARSET=latin1;

--
-- Dumping data for table `his_accounts`
--

INSERT INTO `his_accounts` (`acc_id`, `acc_name`, `acc_desc`, `acc_type`, `acc_number`, `acc_amount`)
VALUES
(1, 'Individual Retirement Account', '<p>IRA&amp;rsquo;s are simply an account where you stash your money for
retirement. The concept is pretty simple, your account balance is not taxed UNTIL you withdraw, at which
```

```
point you pay the taxes there. This allows you to grow your account with interest without taxes taking away from the balance. The net result is you earn more money.</p>', 'Payable Account', '518703294', '25700'),
(2, 'Equity Bank', '<p>Find <em>bank account</em> stock <em>images</em> in HD and millions of other royalty-free stock photos, illustrations and vectors in the Shutterstock collection. Thousands of new</p>', 'Receivable Account', '753680912', '12566'),
(3, 'Test Account Name', '<p>This is a demo test</p>', 'Payable Account', '620157843', '1100');

-- --------------------------------------------------------

--
-- Table structure for table `his_admin`
--

CREATE TABLE `his_admin` (
  `ad_id` int(20) NOT NULL,
  `ad_fname` varchar(200) DEFAULT NULL,
  `ad_lname` varchar(200) DEFAULT NULL,
  `ad_email` varchar(200) DEFAULT NULL,
  `ad_pwd` varchar(200) DEFAULT NULL,
  `ad_dpic` varchar(200) DEFAULT NULL
) ENGINE=InnoDB DEFAULT CHARSET=latin1;

--
-- Dumping data for table `his_admin`
--

INSERT INTO `his_admin` (`ad_id`, `ad_fname`, `ad_lname`, `ad_email`, `ad_pwd`, `ad_dpic`) VALUES
(1, 'System', 'Administrator', 'admin@mail.com', '4c7f5919e957f354d57243d37f223cf31e9e7181', 'doc-icon.png');

-- --------------------------------------------------------

--
-- Table structure for table `his_assets`
--

CREATE TABLE `his_assets` (
  `asst_id` int(20) NOT NULL,
  `asst_name` varchar(200) DEFAULT NULL,
  `asst_desc` longtext DEFAULT NULL,
  `asst_vendor` varchar(200) DEFAULT NULL,
  `asst_status` varchar(200) DEFAULT NULL,
  `asst_dept` varchar(200) DEFAULT NULL
) ENGINE=InnoDB DEFAULT CHARSET=latin1;

-- --------------------------------------------------------

--
```

```
-- Table structure for table `his_docs`
--

CREATE TABLE `his_docs` (
  `doc_id` int(20) NOT NULL,
  `doc_fname` varchar(200) DEFAULT NULL,
  `doc_lname` varchar(200) DEFAULT NULL,
  `doc_email` varchar(200) DEFAULT NULL,
  `doc_pwd` varchar(200) DEFAULT NULL,
  `doc_dept` varchar(200) DEFAULT NULL,
  `doc_number` varchar(200) DEFAULT NULL,
  `doc_dpic` varchar(200) DEFAULT NULL
) ENGINE=InnoDB DEFAULT CHARSET=latin1;

--
-- Dumping data for table `his_docs`
--

INSERT INTO `his_docs` (`doc_id`, `doc_fname`, `doc_lname`, `doc_email`, `doc_pwd`, `doc_dept`,
`doc_number`, `doc_dpic`) VALUES
(5, 'Aletha', 'White', 'aletha@mail.com', 'dce0b27ba675df41e9cc07af80ec59c475810824', 'Laboratory',
'BKTWQ', 'defaultimg.jpg'),
(6, 'TUYISENGE', 'Jean Claude', 'claudenesta09@gmail.com',
'55c3b5386c486feb662a0785f340938f518d547f', 'Surgery | Theatre', 'YDS7L', 'Photo.jpg'),
(12, 'Jessica', 'Spencer', 'jessica@mail.com', 'dce0b27ba675df41e9cc07af80ec59c475810824', 'Accounting',
'5VIFT', 'usric.png');

-- --------------------------------------------------------

--
-- Table structure for table `his_equipments`
--

CREATE TABLE `his_equipments` (
  `eqp_id` int(20) NOT NULL,
  `eqp_code` varchar(200) DEFAULT NULL,
  `eqp_name` varchar(200) DEFAULT NULL,
  `eqp_vendor` varchar(200) DEFAULT NULL,
  `eqp_desc` longtext DEFAULT NULL,
  `eqp_dept` varchar(200) DEFAULT NULL,
  `eqp_status` varchar(200) DEFAULT NULL,
  `eqp_qty` varchar(200) DEFAULT NULL
) ENGINE=InnoDB DEFAULT CHARSET=latin1;

--
-- Dumping data for table `his_equipments`
--
```

```
INSERT INTO `his_equipments` (`eqp_id`, `eqp_code`, `eqp_name`, `eqp_vendor`, `eqp_desc`, `eqp_dept`,
`eqp_status`, `eqp_qty`) VALUES
(2, '178640239', 'TestTubes', 'Casio', '<p>Testtubes are used to perform lab tests--</p>', 'Laboratory',
'Functioning', '700000'),
(3, '052367981', 'Surgical Robot', 'Nexus', '<p>Surgical Robots aid in surgey process.</p>', 'Surgical | Theatre',
'Functioning', '100');

-- --------------------------------------------------------

--
-- Table structure for table `his_laboratory`
--

CREATE TABLE `his_laboratory` (
  `lab_id` int(20) NOT NULL,
  `lab_pat_name` varchar(200) DEFAULT NULL,
  `lab_pat_ailment` varchar(200) DEFAULT NULL,
  `lab_pat_number` varchar(200) DEFAULT NULL,
  `lab_pat_tests` longtext DEFAULT NULL,
  `lab_pat_results` longtext DEFAULT NULL,
  `lab_number` varchar(200) DEFAULT NULL,
  `lab_date_rec` timestamp NULL DEFAULT current_timestamp() ON UPDATE current_timestamp()
) ENGINE=InnoDB DEFAULT CHARSET=latin1;

--
-- Dumping data for table `his_laboratory`
--

INSERT INTO `his_laboratory` (`lab_id`, `lab_pat_name`, `lab_pat_ailment`, `lab_pat_number`,
`lab_pat_tests`, `lab_pat_results`, `lab_number`, `lab_date_rec`) VALUES
(6, 'TUYISENGE Jean Claude', 'RSSB', 'M5E9V', '<p>Malera Detected</p><p>Headache</p>', NULL,
'6UBXH', '2024-03-29 09:48:06'),
(7, 'NTUHINYURWA Jean Bosco', 'RSSB', '1ODBR', '<p>Blood </p><p>urine</p>',
'<p>Maleria </p>', 'MB3HO', '2024-03-29 10:02:26');

-- --------------------------------------------------------

--
-- Table structure for table `his_medical_records`
--

CREATE TABLE `his_medical_records` (
  `mdr_id` int(20) NOT NULL,
  `mdr_number` varchar(200) DEFAULT NULL,
  `mdr_pat_name` varchar(200) DEFAULT NULL,
  `mdr_pat_adr` varchar(200) DEFAULT NULL,
  `mdr_pat_age` varchar(200) DEFAULT NULL,
  `mdr_pat_ailment` varchar(200) DEFAULT NULL,
```

```
  `mdr_pat_number` varchar(200) DEFAULT NULL,
  `mdr_pat_prescr` longtext DEFAULT NULL,
  `mdr_date_rec` timestamp(4) NOT NULL DEFAULT current_timestamp(4) ON UPDATE
current_timestamp(4)
) ENGINE=InnoDB DEFAULT CHARSET=latin1;

--
-- Dumping data for table `his_medical_records`
--

INSERT INTO `his_medical_records` (`mdr_id`, `mdr_number`, `mdr_pat_name`, `mdr_pat_adr`,
`mdr_pat_age`, `mdr_pat_ailment`, `mdr_pat_number`, `mdr_pat_prescr`, `mdr_date_rec`) VALUES
(1, 'ZNXI4', 'John Doe', '12 900 Los Angeles', '35', 'Malaria', 'RAV6C', '<ul><li>Combination of atovaquone
and proguanil (Malarone)</li><li>Quinine sulfate (Qualaquin) with doxycycline (Vibramycin, Monodox,
others)</li><li>Mefloquine.</li><li>Primaquine phosphate.</li></ul>', '2020-01-11 15:03:05.9839'),
(2, 'MIA9P', 'Cynthia Connolly', '9 Hill Haven Drive', '22', 'Demo Test', '3Z14K', NULL, '2022-10-18
17:07:46.7306'),
(3, 'F1ZHQ', 'Michael White', '60 Radford Street', '30', 'Demo Test', 'DCRI8', NULL, '2022-10-18
17:08:35.7938'),
(4, 'ZLN0Q', 'Lawrence Bischof', '82 Bryan Street', '32', 'Demo Test', 'ISL1E',
'<ol><li>sample</li><li>sampl</li><li>sample</li><li>sample</li></ol>', '2022-10-20 17:22:15.7034');

-- --------------------------------------------------------

--
-- Table structure for table `his_patients`
--
```