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TAMPERE UNIVERSITY OF TECHNOLOGY

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# ARCHITECTURAL DESIGN OF THE NATIONAL HEALTH INFORMATION SYSTEM FOR RWANDA

Master of Science thesis

Examiner: Assoc. Prof. Alpo Värri
Examiner and topic approved by the Faculty Council of Computing and Electrical Engineering on 13 January 2016

# ABSTRACT

**FERDINAND MURIYESU: Architectural Design of the National Health Information System for Rwanda**
Tampere University of Technology
Master of Science Thesis, 63 pages, 1 Appendix pages
May 2016
Master's Degree Programme in Information Technology
Major: Information Technology for Health and Biology
Examiner: Associate Professor Alpo Värri

Keywords: national health information system, electronic medical record, electronic health record, health information system architecture.

The use of information technology in healthcare services can improve the quality of care. The large amount of research has demonstrated the role of the use of Information and communication technology (ICT) solutions to overcome the challenges in patient information management. One of the challenges is the healthcare information sharing between providers. In high income countries, the challenge of exchanging information is almost solved. Nearly all high income countries have implemented a national healthcare network which connects healthcare providers in the whole country. Furthermore, European Union (EU) aims at the point of cross-border healthcare information exchange which supports the mobility of EU citizens. However, in developing countries, they are not yet ready to take the full advantage of ICT in their healthcare systems.

The main objective of the thesis was to design the architecture of a national health information system for Rwanda, which is a developing country with limited resources. The research was based on three main issues: One was to determine existing health IT solutions in the healthcare system of Rwanda. The second one was to explore how other countries have developed their national health information systems (NHISs). The third was to find out how open source solutions can build a national network for a country. From the research, the components of the architecture have been defined and finally the architecture was designed.

The research started by examining the current situation of ICT solutions in the healthcare system of Rwanda. This showed the progress in implementing certain electronic medical record systems in certain health facilities. However, there is no single hospital with a fully functional system. This step was followed by exploring how other countries implemented their NHIS and it showed that the process varies country by country. It was clear that in developing countries, open source solutions got a large market share contrary to developed countries where proprietary systems are the most used. Finally, open source solutions proved the capability to build a NHIS with different examples of robust open source solutions available in health IT nowadays.

Although it would have been interesting, the thesis does not estimate the financial resources needed for the implementation of the architecture. It is possible to implement the NHIS for Rwanda by using both proprietary and open source solutions. However, the interoperability issue can be mitigated by minimizing different types of electronic medical records in healthcare facilities.

# PREFACE

Finally, the journey of writing the master thesis ends here. The work of this thesis was carried out based on researches in the field of health information systems. The guidance and supervision were provided by Associate Professor Alpo Värri from the department of signal processing of Tampere University of Technology.

Foremost, I would like to express my sincere gratitude towards Associate Professor Alpo Värri for his guidance in supervising this thesis. Without his enthusiasm and motivation, I wouldn't reach to the end of this research. I would like also to thank professors in different progammes of Tampere University of Technology for their support in different ways.

I would like to express my appreciations for the Ministry of Health of the Republic of Rwanda for providing me with unlimited access to the information I needed for this thesis. It is in this way I would like to thank Mr. Erick Gaju in e-Health department for accepting my endless interviews and Dr. Vincent Rusanganwa for guidance within different Rwandan policies.

My thanks extend to my friends in Tampere, I cannot imagine how life would look like without friends in the city where I was the only person from Rwanda. I would like to thank my friends Olli Huopio, Suvi Saveniemi and Jukka Lahtinen for introducing me in Finnish culture. I cannot forget Joseph Ntakirutimana, Alain Itangishaka, Gibson Ndyamukama, Edward Ameyo and Stanley Njenga. I am blessed to be in this circle of amazing people.

Last but not least, I thank my family for unfailing love. Without their love, I wouldn't know the way to school. In particular, I dedicate this work to late Mr. Alfred Munyentwali, without his sacrifice and unconditional support, I could not attend Tampere University of Technology.

Tampere, 25th May, 2016

Ferdinand Muriyesu

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**LIST OF ACRONYMS**

| | |
|---|---|
| ADT | Admission Discharge and Transfer |
| CBHI | Community Based Health Insurance |
| CDS | Clinical Decision Support |
| CPOE | Computerized Physician Order Entry |
| DHC | District Health Committee |
| DHC | District Health Committee |
| DHIS2 | District Health Information System Two |
| EHR | Electronic Health Records |
| e-LIMS | Electronic Logistic Information Management System |
| EMR | Electronic Medical Records |
| HL7 | Health Level Seven |
| HMIS | Health Management Information System |
| ICT | Information and Communication Technology |
| ICT4D | Information and Communication Technology for Development |
| ID | Identity |
| IHE | Integrating Healthcare Enterprise |
| ISO | International Organization for Standardization |
| LIS | Laboratory Information System |
| LOINC | Logical Observation Identifiers Names and Codes |
| MoH | Ministry of Health |
| MRI | Magnetic Resonance Imaging |
| MYICT | Ministry of Youth, Information and Communication Technology |
| NHIS | National Health Information System |
| NICI | National Information and Communication Infrastructure |
| OpenMRS | Open Medical Record System |
| OSS | Open Source Software |
| PACS | Picture Archiving and Communication System |

| | |
|---|---|
| PC | Personal Computer |
| RAMA | la Rwandaise Assurance Maladie |
| RBAC | Role Based Access Control |
| RIS | Radiology Information System |
| RRA | Rwanda Revenue Authority |
| RSB | Rwanda Standards Board |
| RSSB | Rwanda Social Security Board |
| SDO | Standards Developing Organizations |
| SIG | Special Interest Groups |
| SNOMED-CT | Systematized Nomenclature of Medicine – Clinical Terms |
| SOAP | Subjective, Objective, Assessment, Plan |
| VistA | Veterans Health Information Systems and Technology Architecture |
| WHO | World Health Organization |

# 1. INTRODUCTION

The introduction of computers in the modern world has changed the way people work, live, and communicate. This change has reached all industries from agriculture to aerospace. During the 19th century industrial revolution boosted the economy and lead the development of countries. From that era, some countries took the title of industrialized nations due to the presence of industries. However, in 21st century with the arrival of new technologies, information technology seems to be the leader of socio-economic development. The computer technology doesn't know borders. This allows information technology to spread on the entire planet in a shortest time than classic industries which many countries do not have yet.

Due to the need of operations management, industries introduced information technology as a tool to improve their productivity. Different industries introduced computers in their operations early from first computer invention period. The finance industry seems to be the pioneer in using information technology. The healthcare industry was late for ten years to start using information technology compared to finance industry and it has not been disseminated as fast as in finance. The very simple example is that all banks in industrialized countries have their bank systems to manage all operations, until to serving customers with their mobile devices. However, in health care not all hospitals have implemented electronic health record systems in developed countries. When it comes to low and middle income countries, the financial industry is far more computerized compared to the health care sector as well.

In industrialized countries, efforts have been made to computerize health care industry to take full advantage of Information and Communication Technology (ICT). A large number of healthcare providers has implemented Electronic Medical Record (EMR) systems. National Health Information Systems (NHIS) projects have been implemented in many countries. In developed countries where there is the required infrastructure, with the initiative of governments and key stakeholders, implementation of Health Information Technology (Health IT) projects has not been challenging in terms of resources. On the other hand, developing countries still have challenges of policies, poor infrastructures and resources to digitize their healthcare sector.

This research aims to figure out what can be a solution for Health IT in developing countries with the case study of Rwanda. Even though the thesis won't cover the whole national health information system, the effort has been made to explore available resources in Rwanda and find out how the national health information system can be developed. It is in this context the architecture has been designed for nationwide Electronic Health Record (EHR) system for Rwanda. The purpose of the architecture is to demonstrate the fundamental organization of the system with its components. It outlines the relationships of those components and specifies the principles guiding the system design and its evolution.

### 1.1 Thesis objectives

The main goal of this thesis is to design the architectural view of NHIS for Rwanda. The proposed solution in this thesis can also be applied in other developing countries. The specific objectives of the thesis are outlined below:

- To figure out the existing resources in the health information system of Rwanda and available ICT infrastructure.
- To design a logical architecture of a nationwide EHR system for Rwanda. This architecture will give the plan on which the system can be implemented

### 1.2 Methodologies

To work on this thesis topic, qualitative research methodologies have been used:

- Interviews with different parties have been conducted to understand Rwanda health model. Interviews have been conducted especially with e-Health department in the ministry of health of Rwanda.
- Visit healthcare providers in Rwanda to observe existing health IT solutions and we conducted interviews with IT and healthcare professionals.
- To explore other nationwide health information systems in different countries. The internet has been the main tool for search: Google scholar, database like PubMed and springers. The keywords were National e-Health, national health infrastructure, national health information system, health information system in Africa and health information system architecture. Cross-checking publications available on e-Health, to accumulate broad background in this field and e-Health in developing countries.
- To explore available open source EMR systems to evaluate and compare them in order to know if the ones in Rwanda comply with international standards.
- Participate in conference of developers and implementers of open source EHR software, and visit hospitals where open source EHR is in use, in a developed country (Indianapolis, U.S.A).

### 1.3 Scope

This thesis will explore NHIS. At this point, it will basically focus on how the NHIS are designed, how they function and requirements for a country to develop a fully functional NHIS. It will figure out also how the open source EHR software can be the best option for NHIS in developing countries. Finally, the architecture of Rwanda's NHIS will be designed as sample of NHIS in developing country. The thesis will not describe a detailed implementation plan but implementation phases are suggested.

### 1.4 Thesis outline

This thesis consists of three parts. The first part provides the introduction of the thesis and the background of Rwanda in general and specifically Rwanda's ICT profile, health care model and the current situation in implementing the health information system. The second part focuses on exploring HIS. This part will explore how some countries have implemented their NHIS, finding key factors to succeed and challenges. The last part consists of the architectural design for NHIS for Rwanda. The first and second chapter covers the first part of this thesis. Next, the chapter three consists of the background knowledge on health information systems and explores open source EMR solutions. Chapter four consists of NHIS in different countries and possible open source

EHR implementation at national scale. The chapter five presents the architecture of nationwide HER for Rwanda. Chapter six discusses the implementation of that architecture in Rwanda. The last chapter is the conclusions of this thesis that summarize what have been done and recommendations for the future studies.

## 2. RWANDA BACKGROUND

Rwanda is a central east African country with 12 million of inhabitants, on 26,338 km2. In 2000, Rwanda had highest population density in Africa, very high birth rate, it was less urbanized, the poorest among poor countries, it had very high illiteracy with the lowest life expectancy of 49 years. The poverty was widespread at the level of 69% of the entire population living under the poverty line. The country depended only on coffee and tea for its exports earnings. The economy was mainly dominated by subsistence agriculture which involves more than 90% of the population. In addition, Rwanda had a bloody war which ended with the genocide in 1994. The genocide that took over one million lives in 100 days. Given all those problems, it was hard to know where to start to develop this country. The purpose of government then was to create a vision, to dream a better life of its people and work for it. It is in that context Rwanda developed Vision 2020 [1].

The vision 2020, briefly, it is a development program of the government of Rwanda launched in 2000. The aim of this vision is transforming Rwanda into a knowledge-based middle income nation, thereby reducing poverty, health problems and making the nation united and democratic. When the vision was developed, it was clear that the starting point was hard to know the starting point. However, the government managed to prioritize certain areas. In this way, the government acknowledged that there are interdependencies and complementarities between different policies and development. With the prioritization, sectors such as education towards developing professional skills will come a head of industrial and service development [1].

The realization of vision 2020 would be carried across six pillars with cross cutting issues that are observed into all other pillars. The six pillars are: Good governance and a capable state, human resource development and a knowledge based economy, a private sector-led economy, infrastructure development, productive and market oriented agriculture, and regional and international economic integration. These pillars are supported by three cross-cutting elements: gender equality, protection of environment and sustainable natural resource management, science and technology, including ICT [1]. This explains the importance that the government of Rwanda gives to the integration of ICT in all sectors and gender equality promotion as reported by world economic forum [2].

### 2.1 ICT in Rwanda

Information and Communication (ICT) has been revealed as one of cornerstones to speed up Rwandan development. With the vision 2020, Rwanda aims to become a middle income country. It may cost considerable resources to build motorways and railways to drive the socio-economic transformation that Rwanda needs. After missing agricultural and industrial revolution all over in Africa, Rwanda is determined not to miss the digital revolution and is ready to take full advantage of it [1]. With this vision 2020, Rwanda established an ICT development plan named ICT for development (ICT4D). This plan is supposed to be executed in 4 phases and every phase has its policy. The policy of the next phase is developed after evaluating the outcome of the previous. Since 2001, National ICT policy and plan 2001-2005 was followed by National Information and Communication Infrastructure (NICI) Plan 2010 and NICI plan 2015. Those are policies that guided the current ICT profile of Rwanda [3]

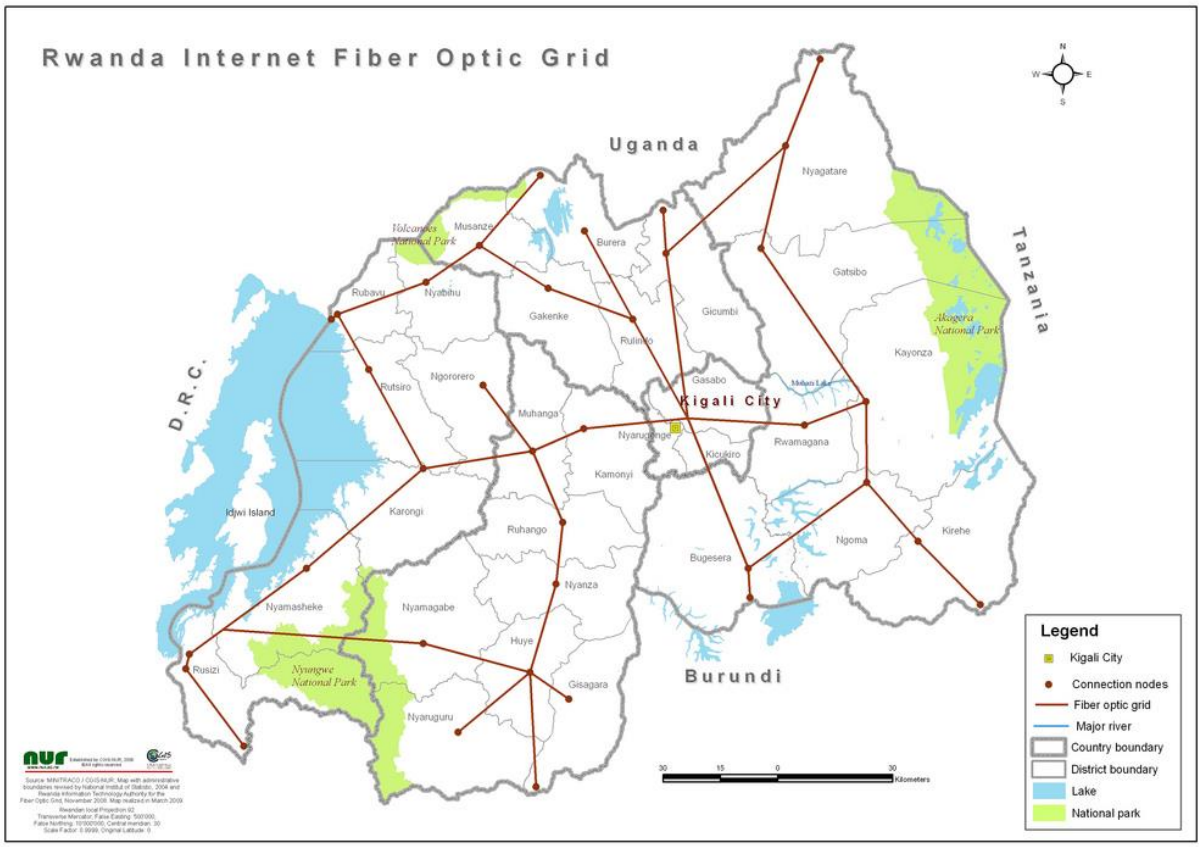


Figure 1: Rwanda Fiber Optic Grid (GIS center, University of Rwanda)

### 2.2 Examples of completed ICT projects

Rwanda is a small (size) country; this might be a disadvantage economically but it is a reality that nobody can change. The only option is to find how to turn this small size into advantages. Normally Rwanda is known as thousand hills country; this is another attribute which makes some infrastructures to cost much, and therefore they are still limited due to economic capacity reasons. However, ICT infrastructures might be less expensive to deploy. Examples of these projects are:

- Rwanda national backbone: This is the fiber optic network which connects all 30 districts of the country, see Figure 1. The district point serves as a hub where other organizations in the district can get a link to the national backbone. The presence of this infrastructure influences different services to be digitized. Nowadays, there are different online services in Rwanda and the population is aware of these facilities.
- Integrated Financial Management Information System (IFMIS): This is the huge system that links different information management systems which are deployed in public institutions to enable the smooth public financial management. It integrates system such as Rwanda Revenue Authority (RRA) information systems, National Bank information systems, Integrated Personnel and Payroll Information System (PPIS), Public Debt Management System (PDMS). With IFMIS, the public finance is managed from the very low level entity of local administration (Sector) to the national level.

- Banking systems: In Rwanda, all commercial banks have online banking systems. Customers can access their banks on internet through either by their mobile devices or browsers on their personal computers (PC).
- Rwanda Development Board: This is the government agency which monitors and promotes different development projects, especially the implementation of ICT projects and investment. The agency provides a large number of online services for the public. For example, business registration is done on the website.
- Immigration office uses different online systems, the most popular is the visa application for non-East African citizens.

There are a large number of projects of this kind completed in Rwanda. The current projects are focusing on the new ICT development strategy under smart Rwanda master plan 2015-2020. The main purpose of this plan is to lead Rwanda to the goal of becoming regional ICT-Hub and enhancing Rwanda's international position as a knowledge-based middle-income nation [3].

### 2.3 The state of the healthcare system in Rwanda

The health sector of Rwanda like other sectors was destroyed by the 1994 genocide. The system is still suffering from the consequences of that tragedy. Although the health status of the population has improved significantly in recent years, the system is still insufficient for covering the population needs. There are not enough health workers compared with the number of people and resources are still limited.

### 2.4 Healthcare model

The health system in Rwanda is a decentralized, multi-tiered system. This means there are different health providers at different levels with different capacities. The health care system works in a hierarchical way. The patient first visits the health center for primary care. There is also another option that a patient can pass through health post. The health post is a new approach to decentralize healthcare services in the community. However, it is mostly used for outreach programs. At the health center, if there is a need, the patient is referred to a district hospital. At this level there are general practitioners who can send the patient to the next level only when it is necessary. The referral hospital is the final level of care Rwanda can provide. The government of Rwanda is working on equipping those hospitals with necessary resources to decrease the high number of cross-border referrals which are expensive. The other approach is to decentralize referral hospitals. The idea is to create one provincial referral hospital in all provinces of Rwanda. This is the way to offload normal referrals hospitals in the capital city. District hospitals will be transferring the patient to provincial hospital before reaching University hospitals.

Apart from this formal health system, there are community based health workers. They are elected by the community, to handle minor problems which don't require a high level of educational background. The community based health workers do a great work especially in preventive care. They can themselves refer a patient to a health center. They contribute in mobilizing people to access to health services in primary care than waiting for visiting hospital. They particularly take care of children under five years and women's health at this level.

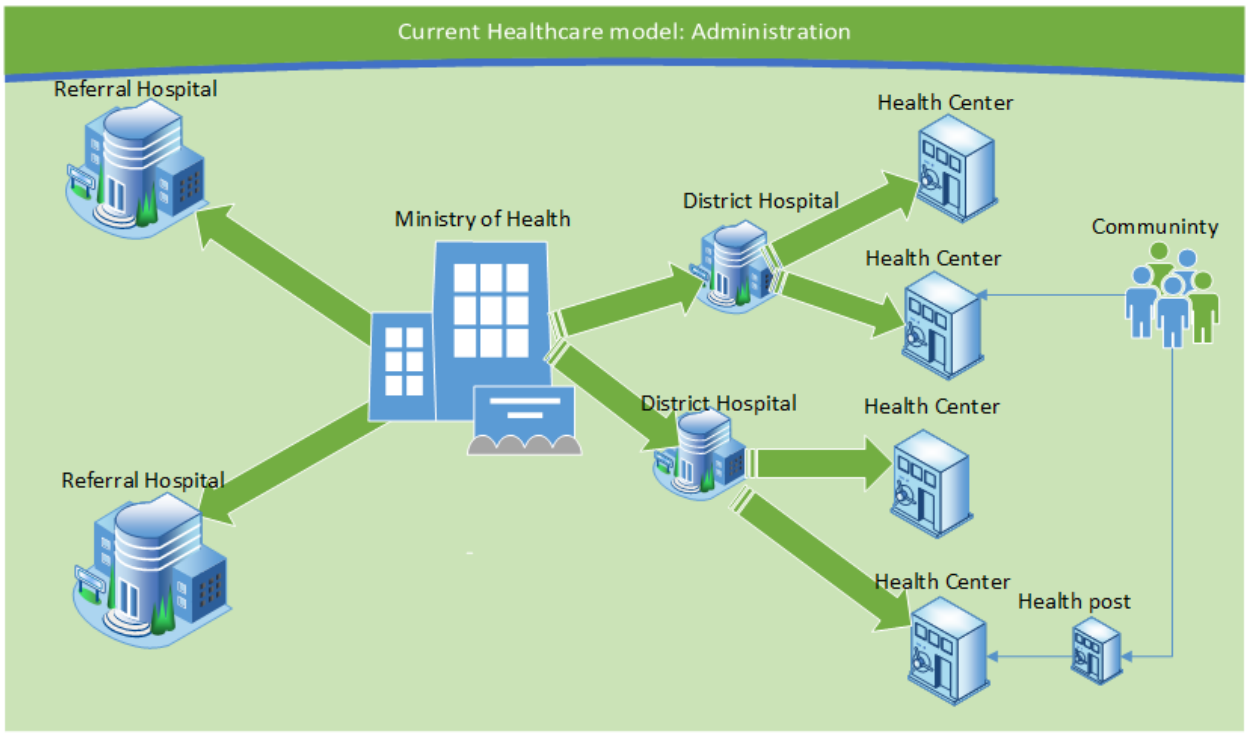


Figure 2: Healthcare model, administration view.

From the point of view of the healthcare delivery process, the Ministry of health (MoH) sets policies and guidelines nationwide. The national health policies and projects are coordinated by the Ministry of health with its agencies such as the Rwanda Biomedical Center. Referral Hospitals don't have anything to do with district hospitals such as supervisions or coordination; they can have a mutual relationship in different programs for example, the trainings of personnel. At district level, the hospital coordinates all health centers in the district. It is the district hospital which supervises different activities at health centers and those two entities are much connected. The district hospital controls the healthcare delivery in the whole district in collaboration with the district local government. Table 1 presents the development of the number of different health care units in Rwanda in recent years.

Table 1: List of health facilities in Rwanda [4]

| Year | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| **National Referral Hospitals** | 4 | 4 | 5 | 5 | 8 |
| **Provincial Hospital** | none | none | none | none | 4 |
| **District Hospitals** | 40 | 40 | 41 | 42 | 35 |
| **Police Hospital** | 1 | 1 | 1 | 1 | 1 |
| **Health Centers** | 436 | 442 | 451 | 465 | 478 |
| **Prison Dispensaries** | 18 | 13 | 16 | 15 | 15 |
| **Health Posts** | 45 | 60 | 60 | 252 | 380 |
| **Private Dispensaries** | 35 | 95 | 114 | 137 | 113 |
| **Private Clinics** | - | - | 60 | 84 | 91 |
| **Community-owned health facilities** | - | - | - | 15 | 15 |

The local government plays a vital role in the administration of all institutions operating in the district. It assumes all government responsibilities at district level. With decentralization policy, the District Health Committee (DHC) coordinates health policies implementation at the district level. It is the one which pays the salaries of the healthcare professionals, and it is in charge of other financing sources. The district manages Community Based Health Insurance (CBHI) which is known also as mutuelle de santé. Therefore, it pays bills to the healthcare providers operating in the district.

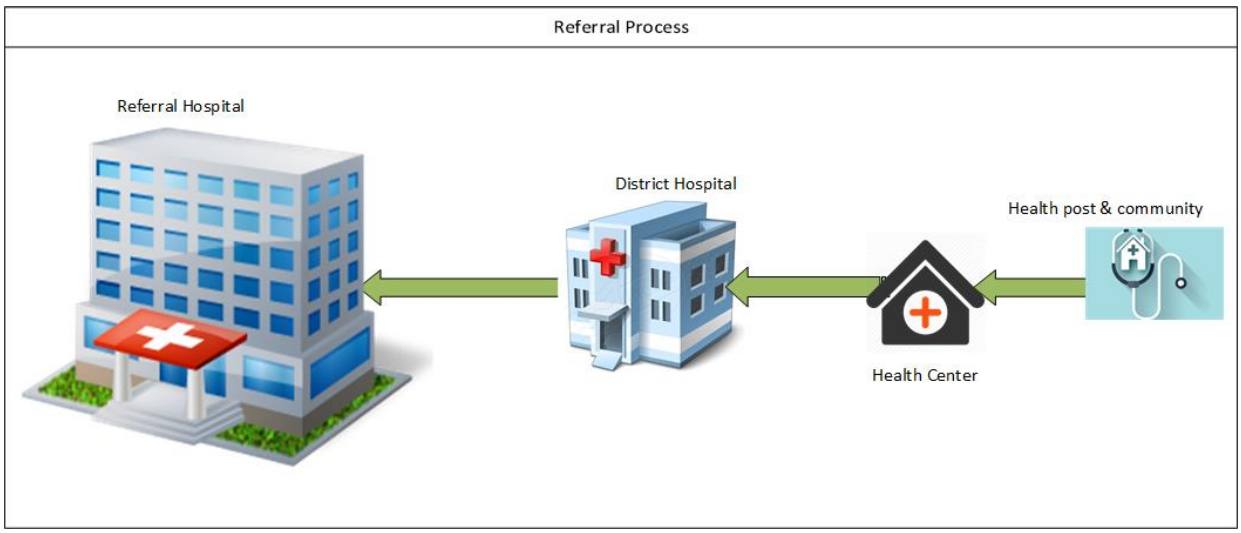


Figure 3: Referral process, the patient moving to higher level.

Referral works in a bottom-up way. The Patient goes first to look for the primary care at the health center. If there is a referral need, then the next level of care is at the district hospital then the district hospital to the referral hospital. Currently, even though the entry point should be the health center, sometimes a patient can go directly to a referral hospital if the insurance allows. Most people who proceed in that way are the wealthiest in the community. The service cost is the same in all hospitals of the same level and health centers. There might be some differences at University hospitals depending on specialties.

### 2.5 Financing model

The health service in Rwanda is financed directly by the government funds and individuals by service fees. The insurance system is working well. The main insurance is the community based health insurance (CBHI), also known as "Mutuelle de santé". The family contributes $6 annually for every member and 10% of each visit costs. This health insurance was covering from 1% of the population in 2000 and 91% in 2010. mutuelle de santé started in 1999 as a pilot program of 54 CBHI schemes across three districts. The scheme partners with the health center and local population started to enroll. It was covering all health services provided at the health center and limited services at district hospital. This pilot program became successful in these districts and the Ministry of health expend it nationwide. There is a plan which is being implemented of merging CBHI with RAMA (la Rwandaise Assurance Maladie) which was covering employees of the government. This merging project will enhance the health care equity to all Rwandans. There are other private insurances which pay health care costs for their affiliated members. It is common in Rwanda that employees contribute together with the employer to pay for premiums with predefined percentages.

### 2.6 e-health in Rwanda

Rwanda initiated e-health projects a decade ago as the country moves toward vision 2020. The integration of ICT in health sector was the starting point in teaching healthcare workers the basic ICT skills. The government supplied basic ICT infrastructures including computers and internet. Table 2 shows the situation of the internet access in healthcare facilities.

Table 2: Internet access use in public health facilities [4]

| | | 2012 | 2013 | 2014 |
|---|---|---|---|---|
| Type of communication | | Number of Health Facilities | Number of Health Facilities | Number of Health Facilities |
| Internet | Wired - DSL or Fiber-optic | 30 | 31 | 31 |
| | Wireless | 29 | 5 | 17 |
| | Mobile internet | 317 | 391 | 404 |
| | No internet | 10 | 33 | 14 |
| | Other (VSAT) | 2 | 7 | 4 |

### 2.6.1 Current e-health projects

As a new country in ICT use, Rwanda is striving to integrate ICT into different sectors. The health sector is one of the priorities to integrate into modern technology. There are different projects initiated:

- **Telemedicine and e-learning project**: System to enable communications and information-transfer services, with the purposes of: ability to carry out telemedicine consultations between district and referral hospitals, and reduction of the number of patients that are transferred from district to referral and outside Rwanda.
- **Electronic Medical Record (OpenMRS)**: The integration of Electronic Medical Records, and chronic disease management functionalities that will enable automated information sharing and facilitate improved patient outcomes.
- **Rwanda Health Management Information System (HMIS)**: a tool for the collection, the validation, the analysis, and the presentation of aggregate statistical data, tailored to integrated health information management activities
- **Electronic Logistic Information Management System (e-LIMS):** This system serves in the supply of medicines across the country. All district pharmacies use it for dispensing medicines to health centers and hospitals in districts.
- **Rwanda Health Information Exchange (R-HIE):** Build interoperability between systems to facilitate information exchange

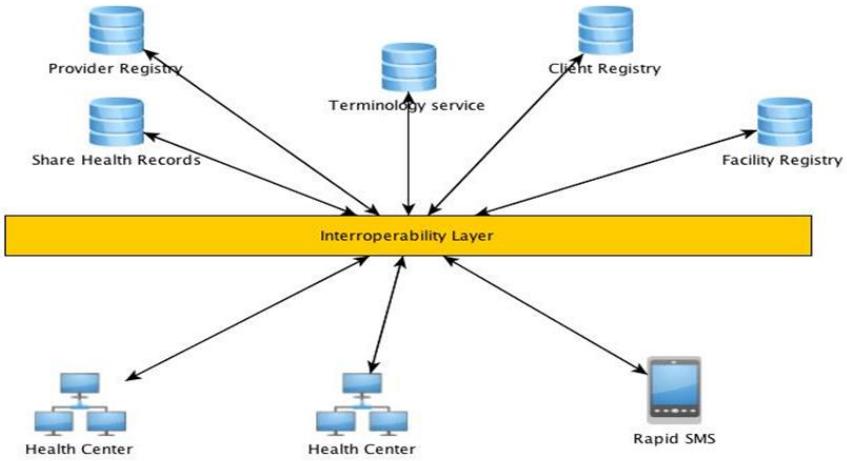


Figure 4: Rwanda health information exchange(R-HIE)

The R-HIE aims at enabling the interoperability between systems. It has been used to integrate RapidSMS into OpenMRS in one district. The ability to integrate other systems removes the barriers data sharing.

- **Health Insurance Information system** (Mutuelle de Santé Membership Module System): The system is for mutuelle membership status checking at healthcare provider before the patient can get treatment.

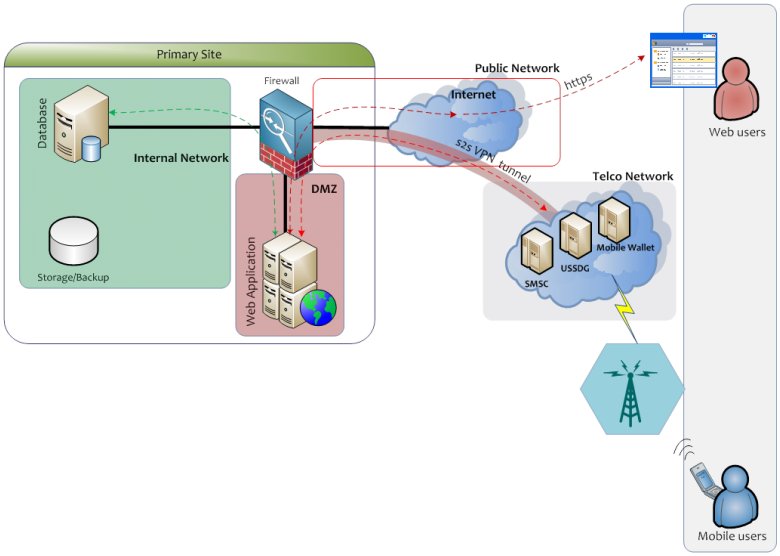


Figure 5: Health Insurance Information system

- **RapidSMS**: This is a mobile application used by community health workers to give reports related to community health. It is intended particularly to follow up of pregnancy, and children under 5 years.

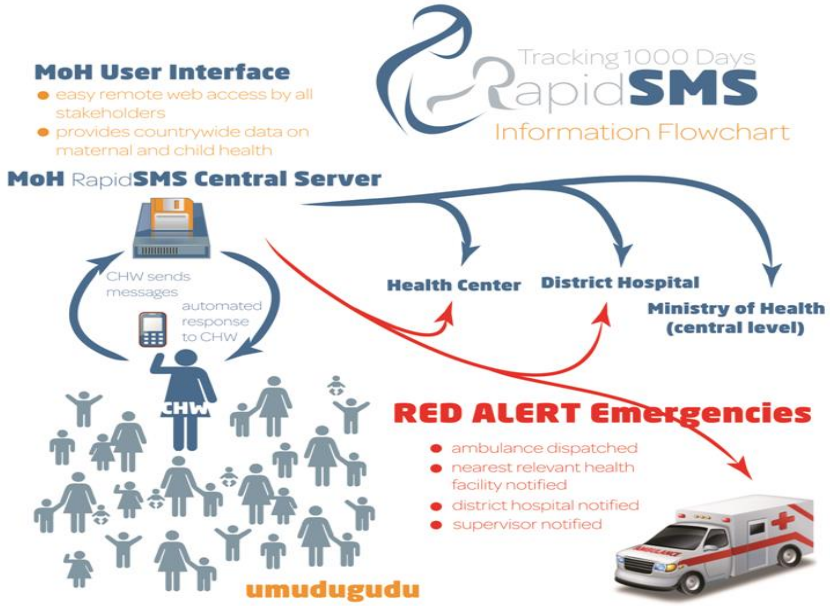


Figure 6: RapidSMS functional view

### 2.6.1 Challenges in the Health Information System in Rwanda

The situation in Rwanda is not dormant, the Government and its stakeholders are working together to push the digitization of healthcare delivery. However, there are different challenges in establishing a robust health information system. The given undergoing projects are not expended to all healthcare providers. This confirms how far it is possible to interconnect hospitals and health centers in Rwanda. Healthcare providers are isolated from each other in terms of data sharing. Therefore, patient's data is duplicated in multiple healthcare facilities.

The population identification is still a challenge in Rwanda, especially in health care delivery: insurance companies have their own identity management for their affiliate members; public institutions use national identity cards as identification document, hospitals use their generated numbers to identify their patients' files (whether paper based or computerized system). The lack of unique patient identification is one of the factors that influence poor management of patient care.

The other challenge is the recording of patient information on paper. The recording of health information on papers has multiple risks such as handwriting errors and readability issues. The other challenge for papers is the classification and maintenance which requires much resources. In addition, papers depreciate slowly within years. In this case there is a high risk of the loss of the patient's health history, which is the scarce resource in treating the health conditions of the subject. The isolated healthcare providers, lack of integrated EMR systems, and lack of unique patient identification result in multiple health information for a single patient, repeating medication efforts, poor resource allocation and makes the patient to be the carrier of health information. The creation of a central repository for healthcare information is one way to connect isolated healthcare providers. In that way, patient information can be available at the point of care. The unique identification is recommended in order to create unique health record for a specific patient. The

central repository will also support the free movements of the patient in the country and can get care at any health care provider without worrying about previous episodes.

## 3. HEALTH INFORMATION SYSTEMS

A health information system is defined in many ways by various authors. Technically, one can see it as information system which is used in healthcare organization. However, information system doesn't necessary imply technology aspects. It may be the organizational approach of processing, managing and disseminating valuable information. In the healthcare environment, a health information system can be understood as data collection, processing, storing and using of the information. The health information system might be a property of a single organization such as a health center or a hospital or a group of organizations such as a regional or national healthcare organizations [5].

### 3.1 Health Information system evolution

In all countries where electronic health records have been implemented, it was not a miracle of one day. It has been a process and every evolution step has come with new opportunities since 1960's when the first health information system started. It was mainly administrative tasks such as admission, discharge and transfer (ADT) and billing [6]. The main purpose was to support organizational finance management, billing, payroll, accounting and reporting systems [7]. After that, problem oriented medical records and SOAP (Subjective, Objective, Assessment and Plan) have been introduced. SOAP is a method of documentation used by healthcare professionals to document patient information for a comprehensive follow up. It includes the information that the patient tells, the results from laboratory and radiology, diagnosis and the future plan [8].

In 1970's Electronic medical records were being used in hospitals and they were the result of integration of Laboratory Information Systems (LIS) and other clinical supports systems. It is in 1980s that Diagnosis Related Groups (DRGs) were introduced as the need of mapping costs to provided service emerged. In this way EMR systems have to integrate departmental systems with hospital billing system. In 1980's, the digitalization started, -Picture Archiving and Communication Systems (PACS) that support digital imaging in radiology settings started to be used. With the internet emerging in 1990's there was a need for sharing information and knowledge in healthcare delivery. Telemedicine has been a solution of communication between physicians to share knowledge on different cases and continuous learning. During this decade, due to the need for data sharing, the interoperability issue raised. There were systems but they couldn't communicate between each other. It was necessary to elaborate standards to enable the interoperability between systems. An example of these are the HL7 standards for clinical information exchange and messaging between applications [9].

In 2000's there were plenty of solutions available in the health IT domain. The issue of sharing clinical information between organizations remained the discussion topic. Standards and regulations have been reviewed and updated regularly to ensure the interoperability of the future systems. It is during this decade that national health information infrastructures have been initiated. Pioneer countries in NHIS like Denmark started with a regional network and finally a nationwide system. European Union noticed the high mobility of EU citizens for work, holidays and studies. These movements are accompanied by different services needed such as healthcare. It is in that way that EU called for a better coordination of health systems and policies across EU states members [10]. This lead to the EU directive 2011/24/EU on patient rights in cross-border healthcare which enables all Europeans to have access to online medical records anywhere in

Europe by 2020. This requires the initiative of every member state to build a comprehensive system that implements interoperability standards.

### 3.2 Health Information Systems Architecture

Architecture is defined as the fundamental organization of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution [11]. It is important to determine an architecture of the system to guide the deployment of system's infrastructures or components. It makes sense to construct a building when the layout of every single material is defined, and the usage of the building is known beforehand. In healthcare, there are various infrastructures to accomplish different tasks in care delivery. The main goal of all resources in a healthcare facility is to treat the patient. However, it might be challenging to efficiently allocate these resources to achieve the main goal of a healthcare organization. The integration of all organizational departments under an enterprise architecture concept may serve as a solution to overcome incompatibility issues within organization subsystems. This integration doesn't only support the work of direct care personnel, but also all people working in the health care organization due to the need of information which has to be fulfilled so that they can achieve high quality and efficient patient care [5].

The integration of organizational departments supports the logic process of healthcare delivery; the process that has steps and policies to follow. This process lies on an infrastructure that serves as a foundation. Infrastructure is not only considered like a foundation [12]. Schatz et al [12] also defined infrastructure in two important words: infra, "the internal support that makes something essential work all the time" and structure, "the universal agreements that enable all the parts to work together". Infrastructure covers both assets and how they work together. However, architecture should be considered before developing the infrastructure. In this way scalability and interoperability will be enabled in advance instead of modifying whole infrastructure to accommodate some changes which may occur at a certain point. Architecture defines the layout of components that make a system.

### 3.3 Health Information Systems integration

In this context, we are talking about the architecture of an integrated health information system. The health information system is considered as a health system asset. It might be the information system used by healthcare institutions [5]. The health information system is dealing with processing of data, information, and knowledge in healthcare environments. It is this information system which can be structured to fit or to change the process of care delivery in organizations. On the other hand, Winter et al [5] demonstrated that if the health information systems in a healthcare organization are not well structured, integrated, managed and operated will evolve chaotically. This evolution will, in long run, lead to poor data quality that result in inefficient and low quality patient care with some excessive costs. The information needed by different groups in a health care organization is likely to be derived from the same data, therefore integration of different information systems is a necessity. This integration of systems obviously requires an integrated health care infrastructure.

The healthcare infrastructure is a complex set of different equipment in laboratories, radiology, physician office, and so on. These equipment support healthcare professionals to achieve the patient care goal. However, it is time consuming if the physician needs to move around different

department to deliver different test orders. In most of the cases, the number of healthcare personnel is limited compared to the demand, therefore the physicians need to increase of the number of the patients that they can treat in short time. As Winter et al argued about systems integration, it is necessary for nearly all healthcare organizations to enable physicians get all patient information in their consultation office. The implementation of EMR systems in healthcare organizations contributed enormously in tracking the patient from the admission to the discharge. This had been enabled by ICT integration in the healthcare environment. The direct access to information increases the productivity of the healthcare organizations. It is argued, however, if the productivity of a hospital should be defined in terms of economical view or by quality of patient care. According to Winter et al, it is much difficult to measure the productivity if the output is considered as quality of patient care. On the other hand, ICT improves the productivity by considering the ratio of the number of cases and full-time personnel. This is the economical aspect of EMR a proactivity factor [13].

This didn't solve the problem of the records duplication or loss of information. The patient remains the main carrier of personal health history. The same data collection is performed when the patient visits the other hospitals. In addition, the patient can change a healthcare provider due to the care quality, specialties and service cost reasons. In the USA, a large number of hospitals implemented EMR systems. However, these systems were not designed as open systems that can integrate data from outside the providers' boundaries [14]. Therefore, it resulted in islands of information systems that cannot communicate or exchange data efficiently [15]. To overcome interoperability issues, different approaches have to be used. It is not only technical but also the willingness and capability to cooperate in order to achieve common goal [16]. The regional agreements to interconnect hospital information systems improves patient safety by reducing errors in medication [12].

### 3.4 Standards implementation

Health care systems like other communicating systems follow some guidelines, rules and standards to meet the requirements. The role of these guidelines is to help systems from different vendors to be able to communicate. The purpose of implementing interoperable EHR systems is to enable cross-organizational health information sharing. The interoperability can be reached by applying different HIT standards. There are different Standards Developing Organizations (SDO) and Special Interest Groups (SIG) that work to address the issue of interoperability between health information systems [17].

To address the interoperability between systems doesn't necessarily depends only on technical standards. There are other processes that are performed to standardize operations in health care organization. To implement a nationwide EHR requires the uniformity of: clinical and business processes of healthcare service providers, information structure for healthcare data, quality of healthcare services, privacy and security regulations and techniques in healthcare services, and so on [17]. Blobel [16] went further by defining interoperability with more advanced perspective. He argues that interoperability describes the ability of organizations to cooperate in order to achieve common goals.

### 3.4.1 International standards

There are different EHR standards for different perspectives of the system. The International Organization of Standardization (ISO) under its Technical committee ISO/TC 215, developed ISO/TS 18308 [18], which defines a common specification for EMR/EHR architecture and requirements. The ISO/TS 18308 standard is the basis in evaluating the quality and efficiency of any EMR/EHR system while ISO/TR 20514 [19] can be used to measure the scope and context of an EMR/EHR system.
As ISO/TC 215 keeps developing and updating health informatics standards, it is important to always update the industry with the necessary knowledge. It is in this regards, Knowledge management of health information standards [20] has been developed to track on health information standards for health system developers and others parties who participate in health information systems implementation. These mentioned standards in this paragraph are useful in system development and implementation and they support interoperability of systems with other standards.

Health Level Seven (HL7) which is one of SDOs, was founded in 1987 and it develops standards for messaging, exchange, sharing, retrieval and integrating health information between systems. The exchange doesn't depend on software vendor, structure or programming language [21]. HL7 standards ensure semantic and syntactic interoperability through system interfaces. One of the reasons to ensure the interoperability is the need for continuity of care [22]. On the other hand, the systems communicate differently, HL7 standards are mostly concerned with clinical information messaging between systems. There exist particular messages appropriate to the context of operation. For example, EMR sends HL7 ADT (Admission Discharge and Transfer) message to other system after patient registration at admission desk.

There are standards for images developed by Digital Imaging and Communication in Medicine (DICOM) that include workflow and data management for radiology images. These standards facilitate the interoperability of medical imaging equipment and information systems [23]. DICOM images has the advantage of including patient information that support the accurate analysis, exchange and search through PACS (Picture Archiving and Communication system) server. The core of DICOM in communication is the consistent file format and networking protocol that connect imaging systems in the radiology settings [24]. As one talks about standards in health IT, it is important to mention also the Integrating Healthcare Enterprise (IHE). It is an initiative of healthcare professionals together with industry that improve the health care information between different systems. IHE defines a technical framework and profiles for the implementation of interoperability standards in healthcare systems to ensure the healthcare information exchange.

### 3.4.2 Coding systems

In healthcare environment, there are commonly used terms and concepts. However, they might be used differently therefore resulting in terminology confusions. The healthcare organizations notified the need for a systematic coding of these concepts and terms in healthcare delivery. It is in this way that different coding systems have been developed and adopted in the healthcare industry. The coding systems cover common medical concepts, observations, diseases names, laboratory tests, procedures and so on [25]

There are different coding systems and one can name some of them: Systematized Nomenclature of Medicine (SNOMED) gives the collection of medical terms in computer processable way [21]. The systems that implement SNOMED vocabulary improve semantic or syntactic interoperability. The World Health Organization (WHO) established the framework to classify diseases with codes, International Classification of Diseases (ICD). The current version is ICD 10. Every disease has been given a code. These codes are recorded in medical records and can be used for further needs such as billing or legal issues. To improve the way laboratory orders and results are communicated the other standard that lists nearly all tests names and laboratory terms has been developed. It is the Logical Observation Identifiers Names Codes (LOINC) that enables the exchange of the laboratory orders, sample management, measurement, and observations until the result reporting [26].

### 3.4.3 Other standards

There are other standardization bodies for software development and technology advancement; for example, for computer networks and server settings. The Institute of Electrical and Electronics Engineers (IEEE) sets different guidelines in the field of technology. The IEEE 11073 family of standards support the interoperability of point of care medical devices and personal health devices [27]

Apart from those international standards bodies, there are also national standardization organizations. Those organizations set standards according to national norms and country specific needs in different areas. Sometimes national standards are derived from international standards. In this way the international standards are amended by adding or restricting some elements to fit national requirements. In Rwanda, there is also standards developing organization which is the member of ISO, Rwanda Standards Board (RBS).

Most standards are voluntary; they are offered to be adopted by people or industry without being mandated by law. However, they might be enforced by law when they are adopted by regulatory organizations for specific domains. There are benefits in adopting international standards in different domains. The products and services that are compliant with international standards ensure the confidence to consumers on safety, reliability, and quality. For example, ISO's standards on secure medical packaging, road safety, and clinical devices are just a selection of those that enhance the safety of the people (ISO).

## 3.5 Healthcare information system security

The patient information is supposed to be personal for the care subject. It is sensitive information that should only be accessed by the physician in order to provide the care. On the other hand, the health information of a person can be disclosed to a family member. Otherwise any other access is guided by the law. The healthcare professionals are ethically and legally culpable in case they handle patient information carelessly. This is a requirement for the healthcare providers to protect patient data disregards the awareness of the patient. The health information security is enforced by the law. It should be accessed only by those who proved the legitimacy for the access [28]. The patient has rights to choose who can have rights to access his or her life information; and it is done through the consent. The consents are kept by healthcare providers and they show the will of the patient [29].

Most of these publications and case studies have been focusing in the developed world where ICT infrastructures are available, personal rights are respected and laws are enforced. It is not the same case in the developing countries. They mostly don't have such laws to protect personal information and the population also doesn't know their rights on that matter. In countries where national health information systems are implemented, to define access rights is the largest task. It can take lot of time even years to find how data will be accessed and who accesses it. In Estonia, a small (size) country with successful NHIS implemented, it took 3 years to define rules and access rights of the system [30]. It involves different parties to have a common agreement on how data should be collected, processed, stored and accessed. There are different attacks to the patient data privacy. It is necessary to define the threats and implement the safeguards that meet the protection requirements.

In the developed countries, identification of people is quite advanced compared to the developing countries. It is likely that in low income countries people don't have any identification component like national identity card. The protection of healthcare information involves different techniques. There will be patient authentication by the system, authenticating health professionals, healthcare organizations and systems themselves such as servers [31]. There are different solutions to maintain the security in this era. Therefore, in system development, the security is placed at a high level and it is given a priority.

### 3.6 Open source software

Open Source Software (OSS) means the software that let its source codes available to the public while proprietary software the source codes are private. This means that the user who adopt an OSS has rights to change the product to meet personal needs, or for innovation. The availability of codes in public gives insights also for new invention. One can say also that OSS is free in terms of price. However, there are many OSS with some costs allies. Those costs go for installation, customization, maintenance and other services that the user can need after acquisition. These costs are the choice of the user. The user can opt to have an OSS free of any charge, but it will require some programming skills and other technical skills to make it fit organization's needs.

Proprietary software, also known as commercial or standard software, are not free. They have closed source code, therefore only the owner of the software has access rights to the code. The software is licensed, this includes terms and conditions on how the software is used, and distributed. The user cannot modify anything on commercial software. It is installed according to the license terms. There is a support contract between the user and the provider of commercial software which makes it easy to be adopted faster in organization. The closeness of the source code is believed to enhance security; however, OSS like Linux and many others removed that constraint for OSS adopters.

The differences between OSS and proprietary software are considered when an organization wants to choose which one of them fit organization's goals. The main difference to focus on is financial resources and ownership. An organization can opt to use OSS not because of lack of purchasing capacity but the will of owning something which can be controlled. It is easy to change Service Company when an organization implemented OSS, but it is hard or even impossible when the commercial software owner disappears.

### 3.7 Open source software in e-health

In fact, there have been different publications relating to open source software in the field of eHealth. The international journal of medical informatics contains plenty of articles with broad backgrounds in this field. However, not so many publications are available on the implementation of health information systems in Africa. This was not a challenge for this thesis as there are enough resources on implementation of open source applications in healthcare IT of developed countries. The famous successful OSS in health IT of USA is VistA which is implemented in all VA (Veteran Administration) hospitals and clinics across the country. It is not in USA only but also in Canada there is OSCAR which is an open source EMR used in a large number of clinics and it is connected to Infoway which is the NHIS for Canada. These two examples show the behavioral change for open source systems use. It may be an opportunity to encourage low income countries to consider open source in EMR systems as good option for their health IT.

In developing countries, they still have problems in providing basic needs to the population and infrastructures are still at a rudimentary level. However, the EMR should not be ignored given its role in improving healthcare quality. Low and middle income countries share the largest part of disease burden with the rest of the world. Therefore, it is important to manage healthcare information efficiently. This helps in allocating interventions accordingly [33]. There are different OSS implemented in developing countries to manage patient records. Most of those applications focus on managing information on HIV/AIDS treatment, malaria and tuberculosis, which are main life threats in low income countries. However, those systems don't help in general routine healthcare delivery management. They contribute much in collecting data related to certain diseases. On the other hand, to have program or disease centered software gave insights of extending these systems to fit all hospital services. The challenge is the cost of fully functional EMR which is high compared to the financial capability of the organization. It is in this context some healthcare providers started installing OSS as their EMR.

OSS has been misunderstood by the world of diverse communities. There is confusion between free software and OSS. The main approach in defining the OSS is the fact of freedom of expression for users. The openness of the software provides a lot of capabilities to develop more features rather than closed systems. The power of the OSS model is demonstrated in the development and the implementation processes which come with interoperability built-in. The other important interest provided by OSS to hospitals and healthcare organizations in general is the ownership. Those organizations don't become prisoners of the vendors [33]. The advantage provided by OSS is the low cost to build a fully operational EMR. In some cases, the main task is the customization of the existing system to fit the organization's needs. This is done by removing or adding different modules according to the context of use.

For the financial reasons and ownership, OSS solutions suit to most of the developing countries [34]. It is the opportunity for developing countries to exploit these solutions and take full advantage of OSS. The interoperability which has been the issue even in developed countries can be reduced to the minor issue also by implementing OSS in hospitals. This gives power of interconnecting healthcare facilities to enable healthcare information exchange between systems.

EMR implementations in developing countries seem to go on very slow speed especially in sub-Saharan Africa. In middle income countries of Asia and Latin-America, EMR implementations are being done faster [34]. There are different projects in implementing EMR for specific programs in sub-Saharan Africa. However, very few hospitals have a full integrated EMR. There are some pilot projects such as the implementation of the Medibaord application in *"Centre Hospitalier Mere-enfant"* in Mali, for example. The Mediboard is a French OSS hospital management information system. It was developed comparing to hospital information system (HIS) used in *"Hopital de Marseille"* in France [34]. This pilot project can give the insight of the possibility to have an OSS fully functional with all the hospital services integrated.

The challenges in implementing EMR in Africa may include: the lack of basic infrastructures, ICT equipment, shortage in electricity, unclear policies, and poor planning due to the lack of financial capacity. Some projects are implemented without plans. This comes mostly with the availability of foreign development funds which are not predictable. For the developing countries, to have a long-term development plan could help in investing in important projects progressively.

### 3.7.1 Examples of OSS in EHR/EMR

There is a large number of OSS in health IT domain. The selection of OSS relevant to the objectives of this thesis is based on three criteria: The availability of software documentation, number and type of implementations and a strong community. The table 3 is filled with random list of OSS in health IT. The list is found on Google search engine. However, it doesn't contain all OSS that can be found. At the end, five OSS have been selected based on mentioned criteria for description and evaluation. These five OSS are selected also because of their popularity in both high and low income countries. The additional consideration for OSS in health IT is the approach used in system development. Therefore, doctor-patient counter, and hospital management approaches are advantageous for OSS implementers. The following OSS have been selected for description and overview due to their popularity: VistA, OpenEMR, OpenMRS, OpenClinic, and OSCAR

Table 3: Some Open source EHR solutions [35]

| Software | Technologies | Implementation level |
|---|---|---|
| **OpenEMR** | MySQL, PHP | Pakistan, Puerto Rico, Australia, Sweden, Holland, Israel, India, Malaysia, Nepal, Indonesia, Bermuda, Armenia, Kenya and Greece |
| **OpenMRS** | MySQL, Java | South Africa, Kenya, Rwanda, Lesotho, Zimbabwe, Mozambique, Uganda, Tanzania, Haiti, India, US, and others |
| **VistA** | MUMPS, Delphi, Kylix, Fileman | Mainly US, Jordan, Germany, Finland, Nigeria, Egypt and others |
| **OpenVistA** | MySQL, XPCOM, Javascript, HTML | US, Turkey, Egypt |
| **PatientOS** | JDBS, PostgreSQL, Java, Swing | Canada, United Kingdom, US |
| **GNUmed** | PostgreSQL, Python | India, Russia, China, Brazil, Colombia, Australia, South Africa, United Kingdom, US |
| **ZEPRS** | MySQL, Apacje derby, Ajax, Java, Quartz | Used in Zambia. |
| **Tolven** | JDBC, SQL, Java, JavaScript | US, Europe and Pacific Asia |
| **GNU Health** | Tryton, PostgreSQL, Python, Android | Argentina, Jamaica, Kenya, Laos, West India, Indonesia |
| **OpenClinic** | PHP, MySQL | Belgium, DRC, Rwanda, Burundi |
| **OSCAR** | JSP, Java and MySQL | Canada, Argentina, Kenya, Ecuador |

### 3.7.2 VistA

VistA (Veterans Health Information Systems and Technology Architecture), it is a health information system developed by US Veteran Affairs and it is implemented across all Veterans hospitals and clinics [36]. There is no license required to implement VistA in US as it was developed using public funds. The federal government encourages hospitals to implement VistA due to its success compared to other systems. This is also in the purpose of the government of US to digitize healthcare by the end of 2015. This system has become public and they made it open source to let it be deployed in developing countries free of charge. The Massachusetts General Hospital Utility Multi-Programming System (MUMPS) which is the programming language used in developing VistA had a replicate of its open source version too. This system has been proved to be functional in hospitals and it is compatible with new emerging systems. The challenge with VistA is its installation which takes several hours and an old user interface. However, worldVistA, which is a non-profit organization has developed a script that can install VistA, GT-M (Greyston Technology-MUMPS) and CPRS (Computerized Patient Record System) in a short time on Linux. The system can be modified to fit any kind of healthcare provider. There are service companies around US to provide installation and maintenance services for hospitals that have implemented this system.

It is compliant with international standards as EHR to serve any type of healthcare provider. Its CPRS (Computerized Patient Record System) is the preference for physicians that have medical training in USA medical schools. This can also serve as a nation health information system given the interconnections already done in USA Veteran Affairs (VA) hospitals and clinics. It is not popular in Africa but there are some implementations in Egypt, Nigeria and Kenya. However, there is success story in Kingdom of Jordan where VistA has been selected as an EHR to be implemented in all public hospitals. In Jordan, the government embraced the implementation national health information system from the scratch by using open source. However, even though it is the OSS, the government invested amount of money especially in recruiting staff for the project. There is one central database which serve as national repository, but this doesn't necessarily imply that it is a good implementation in terms of data security as it can be single point of failure or result into load balancing issues.

### 3.7.3 OpenEMR

OpenEMR is free and open source electronic health record and medical practice management system. It is platform independent, therefore it can run over large number of operating systems [37]. It is one of popular Open source systems implemented in health IT, mostly because of good reputation and rich features. It has got the certification from the Office of the National Coordinator for Health Information Technology (ONC). It keeps getting the support from large community of volunteers and professionals all over the world. This community maintains the status of the software as free by keeping the spirit of openness, kindness and cooperation. It has all features to manage medical practice in a healthcare facility: patient demographics, patient scheduling, electronic medical records, prescriptions, medical billing, clinical decision support, reporting system, security features, multilanguage support, and a link to a patient portal. With the certification of ONC, it fulfills also Health Insurance Portability and Accountability Act (HIPAA) requirements and meaningful use criteria. It uses Apache as the webserver, MySQL as the database, and it has been developed using PHP as the programming language. The system provides

the role based access control to users, however the fact that there is no emergency access possibility, it doesn't meet full meaningful use II even though it is certified by ONC.

### 3.7.4 OpenMRS

OpenMRS is one of the popular Open source EMRs in developing countries, it has been started in Kenya. The idea was to find the solution of storing patient information for the future use. It was specific for HIV/AIDS patient information that was an emergency at a time. However, the system has evolved from the community to hospitals. University Hospital of Mirebalais in Haiti implemented full functional OpenMRS EMR [38]. It is built based on the doctor-patient counter approach. The doctor is capable to fill different forms during the patient visit. The data model is based on a concept dictionary [39]. The concept dictionary combines all questions and answers that can be assigned to a patient. OpenMRS concepts have also different data types: some are numeric, text, Boolean, and coded. The current work is to add different modules to fit all hospital units so that it can serve as a Hospital Information Management System. It uses MySQL database, Java and JavaScript. HL7 standards are used for messaging and clinical information exchange between systems.

It has gained a large community of developers and implementers that makes it dynamic and the network keeps growing. This OSS has the particularity of involving local developers and implementers in software development. That makes it evolve faster beyond expectation of its pioneers. The other influence on its development is the partnership with Google summer code. With this partnership, OpenMRS mangers offer internships to programmers in Google. During Google summer code, interns focus on certain projects to improve OpenMRS functionalities. It is not only Google internships but also Partners in Health collaborates with local universities to provide trainings to programmers and implementers communities. Furthermore, this OSS is developed with the idea of allowing the implementers to have very minimal technical skills. However, system analysis and healthcare information structure expertise are important resources. At the best of the author's knowledge this OSS is the most promising to serving EMR solutions in countries with limited financial and technical assets.

If OpenMRS has gained a larger market in developing countries than other open source EMRs. It doesn't necessarily mean that it is the best OSS for EMR in Africa. This might have been influenced by the support from World Health Organization (WHO) and Rockefeller Foundation especially in tackling the HIV/AIDS data management issue [40]. This has made it popular in Africa. Apart from the WHO support, OpenMRS has developed large community networks globally. This contributes in its evolution which makes it a dynamic project [41] and easy to be adopted especially in Africa.

### 3.7.5 OpenClinic

OpenClinic is an open source integrated hospital information management system. The featuring modules are administration, financial, laboratory, radiology, pharmacy, and statistical reports [42]. It implements international standards such as logical observation identifier names and codes (LOINC), international classification of diseases (ICDx), systematized nomenclature of medicine-clinical terms (SNOMED-CT), and international classification of primary care (ICPC-2). This system is available in multiple languages: French, English, Spanish, Portuguese and Dutch. It can be installed on different platforms such as Windows, Ubuntu and Fedora. It has user friendly interface which can be customized to meet user requirements. It is developed using Java,

JavaScript and JSP. The system is implemented in different countries, both high to low income countries. It has fifteen installations in Rwanda, five in Democratic Republic of Congo (DRC), four in Burundi and one in Mali. It can cover the hospital with maximum of 700 users. This system is used in one of teaching hospitals in Rwanda [42].

### 3.7.6 OSCAR

OSCAR is an electronic medical record system, containing health care information with full billing capabilities, chronic disease management tools, prescription module, scheduling and many other features. It can run locally in an office setting or be accessed over the internet. OSCAR is a comprehensive Clinical Management system with sophisticated modules and a high level of security. The system is flexible. It is a free open source software. However, there are fetureas that are available for only users who signed terms of use (TOU) agreement. The system uses secure socket technology similar to one of online banking to ensure the data security. The backup system is built in, and it is performed every night. It also provides the capability of audit trail, to be able to track accesses and tasks carried out. It requires minimal hardware settings which makes it to be affordable by users with limited resources. It is mostly used in Canada where it has originated from and few developing countries in South America and Kenya in Africa. There are service providers who can sell certain services to OSCAR implementers, which is common for most of OSS. However, when the user can manage to perform all tasks in deploying and use of OSCAR, the system is totally free of charge [43]

### 3.8 Open Source EHR systems evaluation

The number of OSS available in health IT keeps growing. Most of them can perform the same tasks. However, all of them do not work in the same way and they are developed under different interests. Some are developed from existing solutions, and others are developed to fit alike organizations. It is sometimes challenging, for an organization, to be able to choose the right OSS which will satisfy its operations. There are different criteria to consider in evaluating maturity of software:

- **Word of mouth**: This criterion is powerful, someone doesn't need to do more research on the open source with large popularity and good reputation. What people say about that software can influence the user to choose it. There are such kinds of open source which don't need really much examination since they are used by large number of users. Those are powerful open source software such as Linux, Apache web server, samba, etc.
- **Standards and interoperability:** The software which is not compatible with other systems is not recommended at all. The best system is the one which is able to communicate with others, share data with others. In this way the user doesn't need to learn new language or complex data format. It should be easy to use according to user experience and be able to communicate with other systems.
- **Status of the project**: Software needs to be updated. Technology brings new innovations and evolution doesn't stop, so the good open source is the one which has ongoing projects to support and update it. The system always will get bugs, so it is important to be sure that those bugs can be fixed. If the OSS projects already closed, it is better not to implement it.
- **Community**: Open source software is built with community support consideration. Before selecting an OSS, it is important to see the communities around it. Developers and implementers communities are important for any open source software. Communities help in software evolution and remote supports.
- **Cost**: OSS is considered to be free. This is true, but it can be totally free only when the implementer doesn't need technical support in installation and maintenance. Some companies are providing such kind of services on reasonable prices depending on the level of implementation. It is important to consider the cost going with extra activities. OSS with some service costs doesn't mean that it is not good for an organization, instead this can influence some implementers who want to make sure there is constant support.

Apart from these general criteria for any OSS, there are also criteria specific for EMR. ISO/TC 215 has developed standards that have been considered in evaluating the consistency of the five mentioned open source EMR systems. These standards [18] for functional requirements and [19] for context of electronic health records system, give the details about functionalities of an EMR to comply with international standards. There are other standards developed by different bodies such as CEN, U.S Institute of Medicine core EHR and OpenEHR. They have all set certain requirements for EHR to ensure interoperability and compatibility. These standards, ISO/TS 18308, technical specifications for an EHR architecture and ISO/TR 20514 for electronic health record, definition, scope and context, have been selected due to their international acceptance and comprehensive description. They provide detailed and clear structured set of requirements which can be compared to analyze EHR system compliance.

For the standard in [18], the main requirements can be summarized in 8 main requirements: structure, process, communication, privacy and security, medical-legal, ethical, consume/cultural consideration, and evolution. Each of those main requirements has got subsections and in order the EHR to fulfill minimal requirements it should have those requirements in [18]. For the standards [19], it gives the way to classify a system in the context of level of implementation. The system can have minimal requirements to be used "minimally functional". At this level, electronic health record system has repository of core patient health information, medical terminology, reference data, patient identification, and archetypes. At this point, the system has already the main functionalities of an EHR. The second level "fully functional" will go further to include advanced functionalities such as security control, workflow management, multimedia and genetic information. The last level is "provider enterprise" level. At this level the system will add functionalities such as administration, billing, and resource management [19]. According to the research across selected OSS in health IT, none fulfills all those three levels. However, some can have certain number of functionalities from all levels.

Table 4: ISO/TS 18308 EHR system requirements

| Structure | Process | Communi-cation | privacy and security | medical-legal | Ethical | consumer/ cultural | Evolution |
|---|---|---|---|---|---|---|---|
| **Record & Data organization, Type and form of data, health concept representation** | Clinical and record process | Messaging and record exchange | Consent management, Access control, data integrity, privacy and confidentiality, audit | Legal use, actors, competency, faithfulness, preservation of context, version control | Support ethical issues | Consumer and cultural issues | EHR architecture and EHR system evolution |

The table 4 contains the summary of electronic health record system's requirements according to ISO/TC 18308 standard. In evaluating a system:

- The structure will show how the record is organized, data organization, and type of forms to collect data, to check whether the system accepts health concepts and how they are represented.
- The process has to prove how clinical process is followed. There are known logical clinical processes to follow. For example, the patient cannot go to a laboratory before triage in normal conditions. The system should also make the record process clear and accurate.
- Communication, this shows how messages are communicated between systems and units, it also demonstrates how capable the system is to exchange records with other systems, for

example how laboratory and doctor consultation modules are linked and exchange records (orders, results)

- Privacy and security, the system should ensure the data security and proves how consent are managed. Access control based on different levels should be implemented. It should also provide the way of auditing the access to avoid non-repudiation and ensure data integrity and confidentiality.
- Medical-legal, gives the ability of auditing what procedures and medications performed to a patient and proves the competency of healthcare professional according to the law. It proves also the openness of records and ensures faithfulness of the system.
- Ethical requirement is important to be considered when evaluating a system. The good system is the one which respect users' ethic. For example, it can be observed in language usage
- Consumer/cultural approach ensure that consumer values and goals are respected in the system and if it takes in account of cultural norms.
- Evolution is a requirement for the system to ensure the scalability. The operational and business model keeps changing with time, organizational structure might change and add new units and departments, therefore the system should prove how it can fit the changes. The system can also change operational model in healthcare provider institution.

### 3.8.1 Evaluation of VistA

We participated in the 32nd VistA community meeting held in Registrienf Institute of Indianapolis University. The meeting explores the progress of different projects and current development on the system. After the meeting there has been a visit at a VA Hospital to observe VistA in action. In addition, we installed VistA on a virtual machine (VM) to explore its features.

The VistA's features are more advanced than OpenMRS or any other OSS in health IT. It has detailed clinical functions, administration functions, infrastructure functions, and patient web portal functions. In addition to the basic clinical functions within a health organization, VistA has the ability to capture complementary therapy, wellness and home care information. However, it doesn't have a billing function as VA hospital services are supposed to be free for veterans and their dependents. Therefore, implementers are responsible to implement a billing system on their own and redesigning the appearance as well. It is compliant with ISO/TC 18308 due to its broader integration of a large number of clinical functionalities and ISO/TR 20514 standards requirements as it is a fully functional EMR. It fits large and complex hospitals.

Apart from ISO standards, VistA meets the standards of National Institute for Standards and Technology (NIST) and Health Insurance Portability and Accountability Act (HIPAA) requirements. One of the mandatory criteria is meaningful use that ensures that a certified EHR technology can communicate with other. Meaningful use is the US Government's program to encourage healthcare providers to adopt EMR use but meaningfully to deliver better quality patient care. This ensures interoperability with other systems. It is mandatory for a health care provider to be able to share patient medical records in the national repository. This can only happen when the system implemented is compliant with standards set by a national agency of standards.

### 3.8.2 Evaluation of OpenEMR

OpenEMR is one of the popular OSSs in health IT. It has been implemented in different countries. It is configurable to meet health facility requirements. It has been analyzed through its

documentation and its demo software. OpenEMR has a logon window, the security is enforced by a combination of user ID and a password. The administrator can define user profile and assign different roles. It doesn't have consent management ability electronically and no audit trail possibility. It is compliant with ISO/TC 18308 standard on some criteria. According to the report of ONC, OpenEMR has managed to get certification of its CPOE (Computerized Provider Order Entry). The user can make prescriptions, laboratory test orders, and diagnostic images electronically. According to ISO/TR 20514, OpenEMR is minimally functional.

### 3.8.3 Evaluation of OpenMRS

To measure how OpenMRS is compliant with international standards for an electronic medical records, we visited hospitals in Rwanda to check how it is used. This system is implemented in a large number of health facilities of Rwanda. It is a web based application which runs locally with server/client settings. The system is rich in health concepts content and the ICD10 is used as coding system. Regarding the security of the system, it is ensured by the login system. The user needs the username and password to log in the system. The users differ by roles, which gives the access control based on user's roles.

We observed also that the system is flexible especially in providing dynamic templates. This is an advantage of this open source software for physicians who are able to create customized forms. Furthermore, it support the clinical documentation by following clinical process. The efficiency of clinical documentation lead to better patient management. The patient management by OpenMRS improved the quality of care in health facilities where this system is implemented. The last but not least, this system generates different reports containing important information for healthcare system in Rwanda.

The system meets almost ISO/TC 18308 standard requirements. However, it doesn't provide audit trail and billing module performs poorly according to the interviewees. At primary care level, the system is only used for HIV patients' management. According to ISO/TR 20514 standard requirements, OpenMRS is still at minimally functional level in Rwandan health IT.

### 3.8.4 Evaluation of OpenClinic

This OSS is built on open IT architecture. Open IT architecture is flexible for future extensions to a larger system. This makes OpenClinic one of most implemented OSS in health IT. In addition, OpenClinic has evolved to enterprise level, as it integrates different systems that run hospital operations such Electronic Medical Record (EMR), Laboratory Information System (LIS), Radiology Information System (RIS) and Pharmacy Information System (PIS). It has a logical health data record organization that meets the comprehensive healthcare process. This makes it familiar to healthcare professionals who use it.

It is compatible with other EMRs, especially the messaging system is powered by HL7 standards. The security is featured by user identification and authentication. The authentication can be done in different ways: by a combination of user ID and a password or a combination of biometric ID such as a fingerprint and a password. The system can monitor accesses and it can deny the access when a user tries the multiple unmatched log on. The role based access control is the main feature to monitor users' accesses. This is done by defining a user profile. Every user of the system is given a defined profile that allows a certain level of system access. There is no consent management; the consent form is filled and signed by the patient or next kin and healthcare

personnel. The audit trail in OpenClinic enables administrators to monitor who accessed what in case of any complaint or any kind of access violation.

It is compliant with ISO/TC 18308 and ISO/TR 20514 standards at different levels. However, its features are advanced in comparison with OpenMRS especially on security features and the billing module. For example, some of the hospitals in Rwanda are in process to shift from OpenClinic to OpenMRS and all interviewees mentioned that they record data into OpenMRS but the billing is performed in OpenClinic.

### 3.8.5 Evaluation of OSCAR

OSCAR is the most popular open source EMR implemented in Canada. It is a fully functional EMR system but it has less implementers outside Canada. It is secured with a combination of User ID and a password. It provides the audit trail and RBAC is configurable. Apart from modern EMR features, it gives the patient the access to their medical records through MyOSCAR. MyOSCAR is totally managed by the patient. This gives the patients the rights to determine who can access his/her electronic records. The healthcare provider has responsibility to transfer the patient records to his/her MyOSCAR by patient request. It has a strong community, so the implementers cannot fear if the developers disappear. The fact that it has been approved to be one of the systems in the Infoway (National Health Information System of Canada). It has gained the credibility among healthcare providers in Canada. This can be confirmed by the number of downloads of OSCAR's applications that shows that 89% of the downloaders are only in Canada.

### 3.8.6 Comparison of the Open Source EHR systems

Although there are criteria to compare open source software in health IT, it is challenging to select one that is perfect. Every software has its advantages and its shortcomings. To select an open source for a National health information system involves different factors. Most of the low income countries might be influenced by external funds. In high income countries, there are different alternatives for health IT solutions. It is no longer the matter of costs but the open standards that support interoperability that influences the adoption of open source EMR systems in developed countries. The table 5 displays the list of certain characters which may influence the selection of an OSS too. However, in Rwanda they have already OpenMRS and OpenClinic in their health facilities. None of the following criteria is a mean of choosing one. All can coexist and the national architecture supports interoperability between them.

The number of downloads is one of criteria that demonstrate the popularity of software. The observation on the source forge repository found out that OpenClinic, OpenMRS and OpenEMR are popular due to the large number of downloads from different countries. The famous VistA is popular in the USA where 70% of all downloads go. On the other hand, OSCAR was downloaded in 12 countries with 89% of all downloads from Canada. The other criteria in table 4 can influence the adoption of one of these five OSS, however, in low income countries most such projects depend on funds. In Sub-Saharan Africa, OpenMRS is popular not because it is preferred by the healthcare providers. The availability of funds and support of WHO might have some influence in adopting OpenMRS at large. It has been an opportunity for many African countries to implement OpenMRS, however, it cannot be the barrier of implementing other OSS in private clinics. On the other hand, it might be preferred to have a small number of EMR systems in order to minimize interoperability issues. The architecture in this thesis doesn't require specific systems. Therefore anyone or the combination of OSS can build a nationwide EHR.

Table 5: Summary of comparison

| **Criteria** | **VistA** | **OpenMRS** | **OpenEMR** | **OpenClinic** | **OSCAR** |
|---|---|---|---|---|---|
| Number of downloads per week | 79 | 1488 | 1078 | 294 | 1045 |
| Number of downloading countries | 8, only US 70% | 79, US 52% | 79, US 47% | 46, US 24% | 12, Canada 89% |
| License | GPL (Apache 2.0) | MPL (Mozilla Public license) | GPL (General Public License) | GPL | GPL |
| Enterprise | Yes | In process | No | Yes | Yes |
| CPOE | Yes | Yes | Yes | Yes | Yes |
| Log in | Yes | Yes | Yes | Yes | Yes |
| Biometric log in | Yes | No | No | Yes | Yes |
| Audit trail | Yes | No | No | Yes | Yes |
| RBAC | Yes | Yes | Yes | Yes | Yes |
| Patient portal | Yes | No | No | No | Yes |
| Internal messaging | No | No | No | Yes | Yes |
| Community support | High in US | High globally | High globally | Medium | High in Canada |
| Updates | Constant releases | Ongoing projects | Ongoing projects | Ongoing projects | Constant releases |
| Consent management | Yes | No | No | No | Yes |
| ISO/TR 20514 | Provider enterprise | Minimally Functional | Minimally Functional | Minimally Functional | Fully Functional |
| ISO/TC 18308 | Fully compliant | 7/8 | 6/8 | Fully compliant | Fully compliant |

## 4. NATIONAL HEALTH INFORMATION SYSTEMS

Any initiative to develop a nationwide health information system requires the high commitment of time and resources. It will necessarily depend on the availability of some basic infrastructures and policies. In developed countries, most of the cases, necessary infrastructures were in place already in 2000. In developing countries, there are a lot of challenges in this sector and many other priorities. For example, it is not common to have a large number of populations with personal computers in their homes in low income countries in comparison with high income countries. However, internet is a tool which is contributing to overcoming certain barriers. It is available in almost all countries, even though it doesn't reach all places. At the moment, telemedicine pilot projects are found in different low income countries. The population doesn't benefit from such projects, however. Hospitals, health professionals and universities take advantage of telemedicine for training and e-learning.

The common approach to build a national health information system is to integrate segmented information residing in all health service institutions and other stakeholders. There are different organizations that need health related information in line with their interests: the government, insurance companies, legal services, police, Universities and research institutions. The result of this integration gives the core knowledge of health status of the population of a country. This gives the image of the health outcome after a certain period of different activities from a given baseline. The availability of correct information is a foundation of decision-making across health sectors [44].

The health information system provides the underpinnings for decision-making and has four key functions: data generation, compilation, analysis and synthesis, and communication and use. The health information system collects data from the health sector and other relevant sectors, analysis the data and ensures their overall quality, relevance and timeliness, and converts data into information for health-related decision-making [44].

According to this approach, one can think that a national health information system is based only on statistical data collected by different organization. These systems are important to improve the health of the population. However, this thesis will not focus on these systems. The specific purpose of this thesis is to find out how electronic medical records can be developed and help health providers to share patient medical history. This cannot be done without thinking about those statistical systems which get data from hospitals. There should be interoperability of different systems operating in the health sector and other involved stakeholders. Therefore, this thesis will focus on electronic health records rather than statistical systems used for health outcome measurements and metrics purposes.

Electronic Health Records (EHR) and electronic Medical records (EMR) are two terms used interchangeably but there are differences. EMR is a legal record created in healthcare facilities and it is the source of data for EHR. EHR gets data from different EMRs of different healthcare organizations. It enables patient information sharing between healthcare providers [45].

In the high income countries, where EHR works at the high level compared with the low income countries, EMR has been developed before having the idea of EHR. This resulted in the challenges of having different and incompatible systems. These systems couldn't communicate and they were unable to share patient information. There was a crucial issue of data duplication, where a single

patient might have different medical records in different health providers. This was time to think about how health providers can share patient information for better healthcare delivery.

It would not be reasonable to destroy incompatible systems in order to build one system for all hospitals. All hospitals don't do the same procedures, they don't treat the same diseases, and levels of specialties are different. The need for sharing important information between systems was to be fixed. Interoperability becomes not only important but mandatory in EMR systems implementation. The implementation of a nationwide health information system offers the solution for healthcare organizations interconnection and interoperability of their systems. However, it involves different factors that may influence or inhibit the implementation. The following sections discuss about these factors.

### 4.1 Key factors supporting NHIS implementation

In order to implement a large project in a country, there are different factors that might accelerate or inhibit the process. They are: political and financing factors, ICT infrastructure, country profile and the healthcare system.

#### 4.1.1 Political support and financing

It has been shown that political power is the highest key enabler in implementing different projects in the country. For developed countries, it might not be challenging to execute a project which has benefits the citizens. When it comes to developing countries, projects implementation depends on the government ruling the country at the time. In this century, things are changing in a better way. Some countries established political stability. The political will is important for any national project execution. For IT area also there should be factors which enable IT solutions innovation. It is possible to find some countries excelling in IT development than other sectors. This might result of efforts by government in promoting ICT integration in different sectors including healthcare. We can find out how different countries managed to implement EHR and what influenced the success.

Estonian Electronic Health Record System: Estonia is one of the three Baltic countries. Since it has got independence from Soviet Union in 1991, the country invested in ICT. It is believed that Estonia is the most wired country in Europe through its e-Government. In 1998, the Estonian Information policy was approved by the government. The policy served as the guiding document of the developing information society. From this political will to transform the society, multiple solutions in health care have increased and finally got the government support. It is in 2006 that the government of Estonia initiated nationwide EHR project as one of the large projects of Estonian Information Society Strategy 2013 [30].

To develop systems of such kind, doesn't only involve IT engineers, it requires different participants for different roles. Different aspects such as ethical, organizational and legal are necessary to be taken into account. It is in this way; the development of a nationwide system involves different parties at different levels. If the political system works well in the country, it will be easy for organizations to find the common ground for partnership in different projects. There are different motivations in the Estonian EHR development, amongst them are the efficient use of health professional labor by avoiding the replication of tasks, reduce paper consumption as a way to save environment, saving post costs, the efficient use of medical resources such as radiology and laboratory equipment, sick leave transmission through the shared tool, the access of billing information by insurance companies and different other services.

The Estonian EHR seems to be more successful in comparison with many other countries, mostly because of good ICT policy execution. The creation of X-road infrastructure enhanced the connection of thousands of e-services available to Estonians. This includes the national EHR and citizens can access their own medical records the same way doctors can see them.

The other initiative supported by political will is the Danish healthcare information system. It is one of pioneers in this area of nationwide EHR. It started with regional organizations, involved in health care delivery, agreement in creating a healthcare portal in 2001 –sundhed.dk. This an official Danish health portal. It provides all related information for both citizens and health professionals. The citizen can access the medical history from this portal by logging into the system with the unique identifier. Different services can be offered online such as communicating with medical professionals, renewing prescription and booking appointments to health providers. In 2003, Danish administrative regions agreed on a single patient record model. This resulted in one EHR within each region. The success of having all hospitals in the region connected paved the way of integrating all Danish health providers into the network. This has been possible with the agreement between government, regions and municipalities in 2006 in what they called "Connected Digital Health in Denmark". This cross-governmental organization coordinated health IT initiatives between healthcare providers to ensure that they follow national health IT strategies.

The strategy for utilizing information technology in the field of social welfare and healthcare in Finland was established by Government in 1996. It had goals of developing seamless service chains with the introduction of ICT, new technologies, with the consideration of systems compatibilities [46].

Sweden established a National Strategy for eHealth which has purpose of providing guidelines for integrating new technologies in healthcare delivery. The coordination was done at national level; the work was conducted in six action areas. The first three areas were building better conditions for ICT in health and elderly and other ones were concerned with improving eHealth solutions to fit patient needs [46].

In the UK, the government initiated the NHIS with the aim of connecting all regions through the national spin. This spin is a central point where all services can be connected. There is a set of information to push on the spin but a large amount of information remains at the local level. One of the purposes to implement these connections is to ease the people's movement, and choice of their healthcare providers. The government agencies have been involved in this project and the target is to get the National Health Service (NHS) paperless by the end of 2018. The UK took the initiative to invest in this project by providing funds but also involving stakeholders, especially clinicians [47].

In general, the will of the government in implementing any project gives the possibility of the success. In all countries where nationwide EHR succeeded, the government initiated and supported the project by providing funds, elaborating necessary policies and bringing together all stakeholders to achieve common objectives. Therefore, the political will is essential in many ways for a NHIS succeeds. The other example is the USA government that has put $19.2 billion to health information technology. This amount is estimated to lead to the better quality of care, the better coordination of care, fewer medical errors, eliminate duplication of services and cost saving. There

are incentives from Medicare and Medicaid to motivate hospitals and physicians to adopt the use of EHR. In 2015, the government put some penalties for doctors who don't adopt the use of EHR by decreasing Medicare payment by 3% [41].

### 4.1.2 ICT Infrastructure

The role of government and policy makers in nationwide projects is indisputable. It is the government which will support the deployment of different ICT infrastructure to connect common services. In health IT projects deployment; it will be an advantage if there are infrastructures available which can facilitate the integration of different services. For example, the identification of country's population, online authentication for services, internet banking systems, the e-tax declaration and so on. The availability of such systems can contribute enormously in building EHR with the compatibility with other systems. On the other hand, the citizen can be authenticated with the same credentials to access different services online.

In healthcare, to have a shared IT infrastructure helps in clinical data exchange between organizations. Organizations should be connected via internet which is common infrastructure. As the clinical data is sensitive, it is necessary to use the secure method for the connection. For example, in Denmark regions are connected by secure intranet, with local authorities and other organizations to share healthcare data. The healthcare data network is supported by VPN (Virtual Private Network) to enable secure links. In Denmark also, there are more than four million standardized medical documents exchanged through the network per month, which is 80% of all communication in the primary healthcare sector [49]. All of those connections have been possible because there were already ICT infrastructures available. In Estonia, from 2002, X-road infrastructure was launched. This infrastructure connects all public services that Estonian government provides to the people. The existence of X-road beforehand supported the connection of healthcare providers and gave the opportunity to make patient electronic health records available online

Briefly, the availability of basic infrastructure can be the starting point in systems implementation. In countries where hospitals have already implemented EMR, the main task will be to be able to exchange data. If EMR systems are developed by different vendors without consideration of the need of information exchange, the interoperability problems occur at the end.

### 4.1.3 Country profile

By country’s profile, one can say the geographic size and size of its population. It is clear that implementation of national projects in large countries is challenging than in small countries. In the large countries, there is involvement of different parties in nationwide projects. As the number of stakeholders grows, the harder it becomes to make decision and coordination. In small countries, stakeholders are a limited number and therefore they come up with decision in a short time. The good example is Estonia, the small country with a small number of population [30] or Belize in Latino-America.

### 4.1.4 National Healthcare Systems model

The healthcare system model influences the development of a NHIS. There are four type of healthcare system models: The Bismarck model, the Beveridge model, the National health

insurance model and out of the pocket model. The Bismarck model uses an insurance system. It is financed by employers and employees through payroll deduction. The system is used in most of the industrialized countries [50]. The Beveridge model implies the government to pay health care through taxes for the entire population, for example in the UK. The National Health Insurance model has elements of both the Beveridge and Bismarck models. It uses private-sector providers, but payment comes from a government-run insurance program that all citizens fund through a premium or tax [51]. The final model is an out-of-pocket model. It is found in the majority of the world. It is used in countries that are too poor or disorganized to provide any kind of national health care system. In these countries, those that have money and can pay for health care get it, and those that do not have money stay sick or die.

These models determine how health care service functions in the country. Some researchers showed that implementation of EMR can be influenced by a healthcare model in the country. The countries with a single payer make the investment in the implementation of EMR and its adoption easier than in countries where they have multiple systems like the USA where all systems are present. The case of the USA can confirm this argument by considering the Veterans hospitals and clinics. These hospitals implemented a health information system (VistA) and they are connected across the USA while other hospitals are still isolated. This has been influenced by the fact that VA hospitals services are 100% paid by government like in the UK by using taxes.

**4.2 National Health Information Systems in low income countries**

Health care is information business; this makes it to depend on accurate data for any decision at different levels of healthcare delivery. From the primary care to teaching hospitals, physicians depend on information to perform any care delivery [32]. High level bodies such as governments and funders need aggregated information for planning and policies development. The fact that this information is important, it is necessary to make it available at any time needed to different users, especially health care professionals. It is indisputable that the efficiency, effectiveness, accountability, and quality of health care at each of these levels depends on having accurate and timely data.

In developed countries, due to the availability of new technological solutions, health information is available from the point of care to the highest levels. This is often influenced by the availability of basic infrastructures and appropriate skills in ICT sector and information management in general. In developed countries, health care providers started implementing health information management systems from its inception in 1960s. It is not the case in developing countries where computers and health informatics are still scarce resources. Due to the poor health IT development, low income countries are insufficient to manage their health systems.

In fact, health information systems in developing countries are still paper based systems. This is the main challenge in managing health care delivery in those countries. There is no sub Saharan African country which has developed modern health IT to provide timely health information. However, there are emerging EMR systems that are being implemented in many developing countries. This has been influenced by international funds, mainly WHO, USAID and DFID. The main purpose was to manage HIV/AIDS, malaria and tuberculosis which are principal threats of life in sub Saharan Africa [32]. These EMRs implemented in developing countries are mainly helpful in managing particular services.

Implementation of certain EMRs in developing countries for some services gave the insight of extending to fully functional EMRs. It is in this context some hospitals have started to install EMRs to support efficient care delivery. Due to financial limitations, it is hard for hospitals in developing countries to implement proprietary EMRs. It is not only financial constraints but local software companies are not competitive to provide or support the solutions in this domain. This gives power to open source EMRs to be the solution for developing countries as mentioned in previously. Even though OSS revealed as solution for developing countries, it doesn't necessarily wake up developing countries to take full advantage of OSS. The main challenge is lack of basic infrastructure and potential skills. However, some projects are undergoing and successful experiences have been observed [32] –implementation of OpenMRS in three countries of East Africa. This gives promise of possibility of digitizing healthcare sector in developing countries.

### 4.3 Open Source EHR systems for a country

NHIS found in high income countries are generally formed by commercial solutions. The availability of the competitive local companies influences the supply of proprietary EMRs in healthcare organizations. Therefore, the countries built a shared system which finally connect health care providers. Given the development process of national health information systems in developed countries, it cannot be the same approach for developing countries. In developing countries, the IT industry is not yet developed in comparison with high income countries. On the other hand, the basic infrastructures in health sector and human resources are not well developed. However, the open source solutions are playing vital role in computerizing healthcare sector in low income countries.

The concern rises on how to develop a national health information system with open source solutions. There are not many models to follow. However, some countries started building their national health information system with open source solutions in recent years. The example is the Kingdom of Jordan. In Jordan, VistA has been implemented in all hospitals as the official EMR. Jordan is a middle income country; this makes it differ from low income countries in sub Saharan Africa. In Jordan there are all basic necessary infrastructures to adopt EMR easily. The only challenge they met was the resistance of physicians to use the system. The fact that Jordan already had basic resources such as human resources, electricity and healthcare infrastructure, the initial investment to adopt the VistA was to provide trainings for local IT engineers on VistA functionalities especially its programming language –MUMPS that was not popular. All the information about implementation of VistA in Jordan was collected during the interview held with implementers who attended the 32nd VistA community meeting in the USA (January 2016). This is the most successful project among others out of theUSA. VistA is successful EMR in the USA with a large network of implementers and companies that contribute different modules or updates. On the other hand, the Jordan model cannot be the same approach for the low income countries. In low income countries, they lack many basics in comparison with Jordan. However, the implementation of OSS EMR in some hospitals of African countries can give insights of further implementations. These systems are not yet at the level of connecting healthcare providers for sharing patient information. The visit to local hospitals in Rwanda revealed that local EMR systems keep medical record locally and they cannot be shared due to the lack of sufficient ICT infrastructure.

The success story of VistA in Jordan can inspire other developing countries that want to implement an open source EMR as a national health information system. However, VistA is the oldest open

source EMR in the industry. It is not yet clear if other open sources can be successful like VistA did in Jordan. On the other hand, it is possible to implement VistA in low income countries. However, it requires local programmers to learn MUMPS. To learn the new programming language might not be the problem but the government might do high investment in trainings. It is not something that a low income country can initiate itself. It was observed that most open source EMR that had been implemented have been funded by international funds, this is not the case for Jordan. In Jordan, the government invested public funds in this project. According to the interviewees, the government created a specialized organization to execute this project. With the examples of already implemented projects in low income countries, the governments need to put some efforts rather than waiting for foreign funds to extend those projects. It is important to set goals with a defined time. It is not mandatory to carry out a whole nationwide project but it can be helpful if there is a long term plan that can be executed progressively.

# 5. ARCHITECTURAL DESIGN FOR RWANDA NHIS

The main task for this thesis is to explore national health information systems and design the architecture that can fit the Rwandan health information system. The architecture for the national health information system requires to check the available resources in healthcare industry and its stakeholders. Therefore, the architecture can be implemented by starting from existing resources. The architecture of a NHIS involves different stakeholders; all partners have their systems, so the integration will basically be completed by enterprise architecture (EA). The EA will show necessary components which link each other to connect the healthcare sector. This architecture also will integrate other organizations that work closely with the healthcare sector.

While all organizations strive to work together and share different data, it is important to harmonize a general health data set and have a common platform with one target of delivering healthcare efficiently to citizens. In this way, it is important to recognize common resources that can be shared by different organizations and place them on the EA efficiently. For example, it is resources consuming for the hospital to have the database for patient demography while the civil registration has the same information.

The health care industry itself is a large and complex enterprise. It requires the implementers of health information systems to choose the enterprise architecture that can integrate the complex health care process. The health care process is not steady, it changes, it evolves, new practices come, and stakeholders influence how hospitals work, and so on. The architecture that might fit well the hospital is the one that allows the integration of new systems without disrupting the current architecture. If some process has to change, the good architecture has to be flexible for changes too.

Microsoft has done the comparison between the top four enterprise architectures methodologies: The Zachman framework, the open group architectural framework (TOGAF), the federal enterprise and the Gartner methodology. The comparison showed that none of these methodologies is the best for any kind of organization. Each of these methodologies has its own strength and weakness. The most important is to know what the organization needs. In that way it is possible to assess the capability of the architecture to bring the business side and technology side together to work towards the same goal.

While these largest four EA methodologies are well described, TOGAF can contribute much in the development of new systems. This method is an open framework that leads the process of developing an architecture step by step with its Architecture Development Method (ADM). The advantage of TOGAF for the case of Rwanda NHIS is the flexibility of the model to start the implementation with existing resources. Otherwise, the application of Zachman model might not be fruitful due to the lack of all required components. The Zachman method is taxonomy, it places every component in the appropriate place to build the system. On the other hand, the TOGAF method gives the system the capability of evolving from existing resources and let the room for improvement.

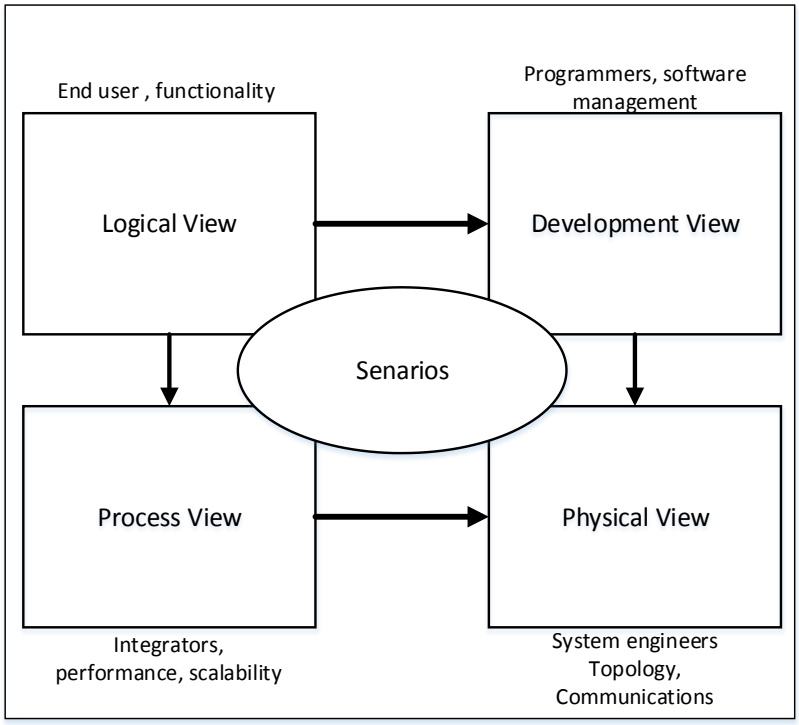


Figure 7: The "4+1" View model [52]

The TOGAF model will also allow the architecture view in 4+1 system view. This system views give to the users the glimpses of their interests into the system. End users will be interested in logical view, system designers and integrators will be interested in the process view, the development view will be the concern for developers, the physical view will be the interests of system designers and finally the scenarios will be the shared interest of all players [52]

**5.1 Information systems that need to be connected**

To develop a national health information system requires to integrate scattered systems in the way that they can share the information they are holding. It is not tailoring the national system as a single project but the capability of integrating each project along the system evolution. Yet, there are different systems in Rwanda's health industry that could be integrated to carry the same mission and get out the value of information technology resources. The design of an architecture is a starting point to integrate separate systems. The following systems are the main components that might be connected to form the NHIS for Rwanda. However, the architecture should be open to allow integration of any other system. In that way, the system evolves without causing any problem.

### 5.1.1 Electronic Medical Record systems

In Rwanda, there are both proprietary and open source EMR systems. Most of the public health facilities implemented OpenMRS while OpenClinic is implemented in 15 health facilities. The only one proprietary EMR system is implemented in one referral hospital. OpenMRS is the one that is implemented in a large number of health facilities: 340 health facilities including all public hospitals. To have OpenMRS in many health facilities doesn't mean that it is fully or even minimally functional in all implementations. According to the Rwandan eHealth department in the ministry of health, only 16 hospitals have implemented full OpenMRS package, other facilities use only HIV/AIDS module to manage HIV patients' information. If one scales the implementation with ISO/TR 20514 standard, it is at the minimal functional level in these 16 facilities where the full package is deployed.

On the other hand, the hospitals that have OpenClinic didn't initiate the implementation themselves. It is the Belgian technical cooperation in Rwanda that supported the implementation. Foreign companies have been hired for OpenClinic implementation. The maintenance and development of OpenClinic is expensive for hospitals in Rwanda. The fact that first implementations didn't involve local developers, it is likely for hospitals to pay expensively the maintenance service from abroad. Despite the maintenance cost challenges, OpenClinic works well.

The only proprietary EMR system is implemented in one referral hospital. It is supposed to be fully functional EMR as ISO/TR 20514 standard defines the scope of EMR. It has the electronic medical record, the pharmacy system, the human resource management system, the laboratory information system, the administrative module comprising accounting and the radiology information system that connect with PACS. The challenge with this system is common for the commercial systems such as the provider bankrupts and quit the business, the delay to any change and costs. The other constraint is that the system was provided by a foreign company which doesn't even have a representative in the country.

One of the components that prove the quality of an EMR is its Computerized Physician Order Entry (CPOE). CPOE are the systems that allow physicians to electronically place medication orders, as well as the laboratory, radiology, pharmacy, admission, procedures and referral orders. They decrease the delay in order distribution, resource allocation and order compilation. The CPOE systems, when implemented together with Clinical Decision support systems (CDS) improve the patient safety by reducing errors related to drug interaction, patient's allergies to specific medicine, medication contraindication and any other health conditions of the patient. The role of CDS is to provide real-time feedback on the diagnostic and treatment background of patient [52].

Finally, an integrated EMR system requires a comprehensive network. The minimum local area network (LAN) is required in all health facilities that plan to implement an EMR. Therefore, the installation and configuration of network is prior activity. Apart from the network, it is necessary that every consultation room and other offices have computers. The server room should be equipped with UPSs and air conditioners to support network devices and servers against hazardous power shortage and heat. The following Figure 8 displays a layout of a LAN than can fit a large hospital.

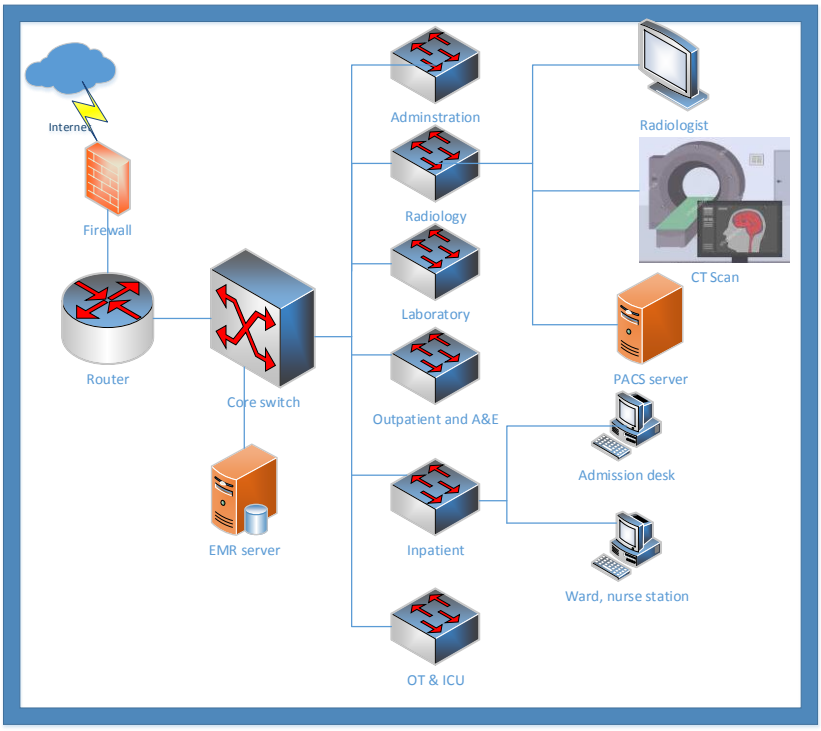


Figure 8: The network architecture for a hospital with different departments.

OT & ICU (Operating Theatre and Intensive Care Unit), A&E (Accident and Emergency), CT scan (Computer Tomography Scan)

The architecture above suggests the network infrastructure that can be installed in the hospital. The entrance of the network is a firewall that serves as security device. The router has all configurations of the network. From the core switch, one can separately configure departments by configuring VLANs or subnetworks. The core switch has L3 capabilities, so it can act as a router. The EMR server is connected to the main switch and it is accessible by the traffic from all departments. This server has the integrated hospital management information system with EMR, LIS, RIS, Administration, human resource and so on. There is an extension of Radiology that shows the separate PACS server.

### 5.1.2 Laboratory Information systems

In Rwanda, there are not many laboratories separated from hospitals. However, there is one national reference laboratory. Its role is to supply necessary materials and consumables to local laboratories and provide guidelines on standards. The referral laboratory has developed the system that helps laboratories to report the test results. However, the system is not yet installed in all hospitals. It is planned that the system will be supplied to all laboratories in that way the sharing of results is feasible. In health information management systems, it is important that physicians can access to the laboratory test results for efficient patient care. According to eHealth department, a physician in any hospital cannot access the national reference laboratory system. This architecture in this thesis shows the way this laboratory information system can be a repository for all laboratories.

The laboratory system architecture integrates the different departments of the laboratory. The capacity of laboratories depends on equipment available and the number of tests that the lab can perform. The laboratories in Rwanda can have different departments, however one of the largest laboratories visited has the following departments: Microbiology, hematology, hormonology, histopathology, bio-chemistry and immune-serology. This laboratory is in a referral hospital; it has different modern analyzing machines. Due to its capacity, it can perform tests from other laboratories. Apart from the visit at that hospital, the interview was conducted with laboratory technicians to find out how LIS works. After the visit and the interview, it has been found that the laboratory in that hospital works well. LIS is integrated with EMR of the hospital. The Physicians can order the tests from their consultation room and get the results on their computers. The challenge is when the lab has to analyze samples from outside the hospital, in that case the results are printed on the paper for the patient.

Figure 9 suggests the architecture of a laboratory system that is integrated within a hospital management information system. It shows the information flow from EMR to LIS. Once the order is accepted, it is sent to the appropriate department for sample collection, analysis. The test results are reported to EMR for physicians or printed out for the patient in case he or she was not admitted in that hospital. The addition component in this architecture is the link to the national reference laboratory system that can serve as test results repository. Apart from the national laboratory, the architecture suggests the link to EHR that will make the results available for the patient too.

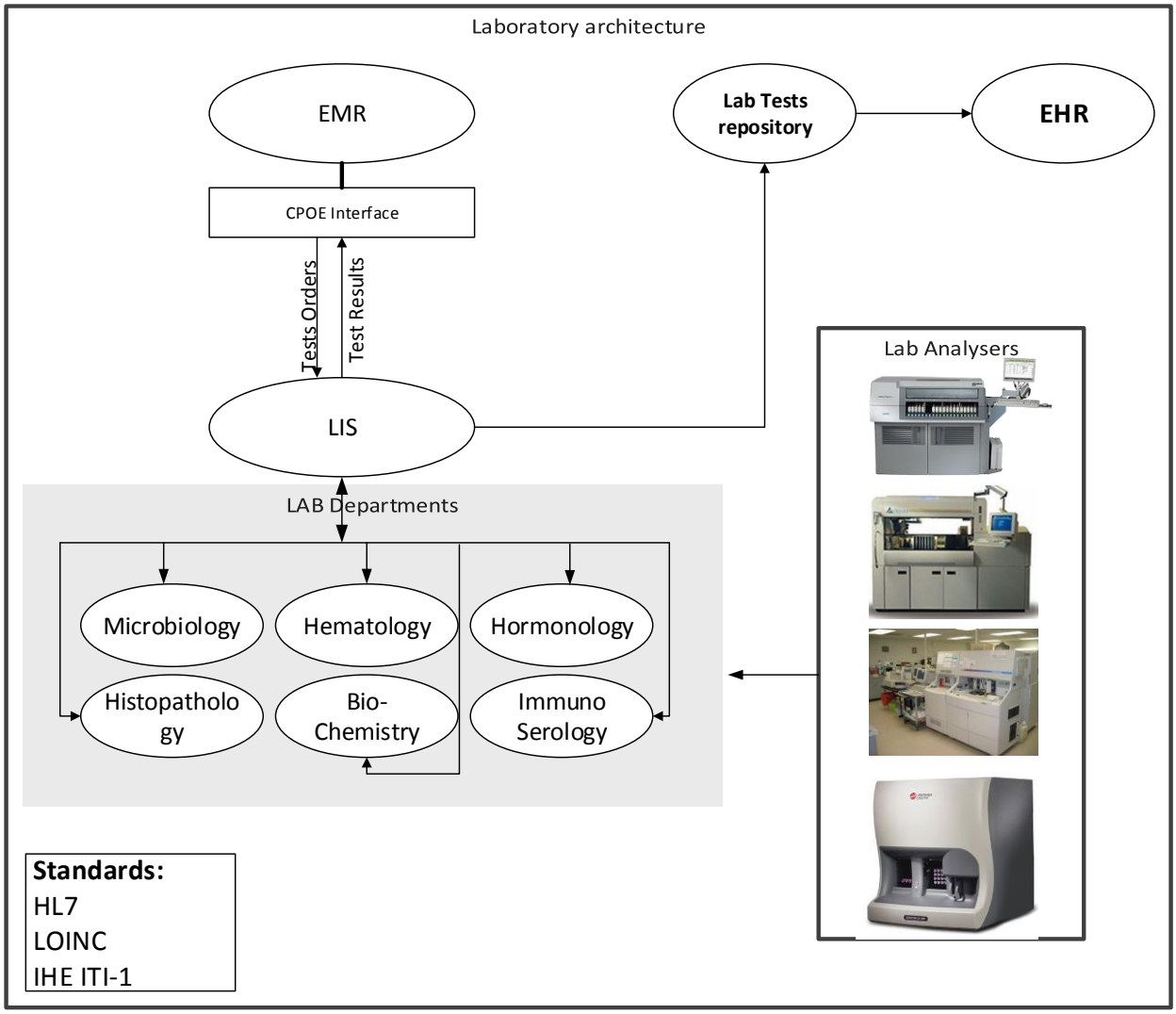


Figure 9: Laboratory architecture

The architecture above, only describes the transmission of information between EMR and LIS when they are already integrated. In this case it doesn't cause much difficulties especially when the vendor or developers for both systems are the same. Most of EMR implemented in large hospitals have LIS integrated as a module, so the interoperability will be resolved in implementation. The other effort is to configure the analyzers interfaces to be able to push the data into LIS. The laboratory can send the test results for the patient into the central repository. IHE suggests a model for document sharing that supports the use of common infrastructure. The model is Centralized Discovery and Retrieve (CDR). Other laboratories or health care providers use cross Enterprise Document Sharing (XDS) query to retrieve the patient information. This model is used with other systems to enable healthcare information sharing nationwide.

### 5.1.3 Radiology information systems

There is one radiology management system in Rwanda. It is implemented in one referral hospital that has a commercial EMR. In teaching hospitals, there are some solutions that help physicians to analyze images. This is common in developing countries, given how expensive radiology equipment are. This means that very few hospitals have CT scan machines. In Rwanda, CT Scans are only in referral hospitals and a MRI machine is in one hospital. However, this cannot be the challenge for the RIS to be developed. In that way hospitals with sufficient capacity can still perform radiology tasks and share information through a central image repository. The architecture suggests the development of five radiology centers that can be fully equipped with all necessary equipment. The idea is to have at least one radiology center in each Rwandan province and the city of Kigali. Figure 10 gives big picture of such centers. These centers will perform the radiology work and share the information with hospitals across the country. Doctors through CPOE will be able to order radiology tests for the patient and the order can be received by the nearest center. The patient can visit the nearest radiology center. This can be the solution for the radiology system in Rwanda given the size of the country.

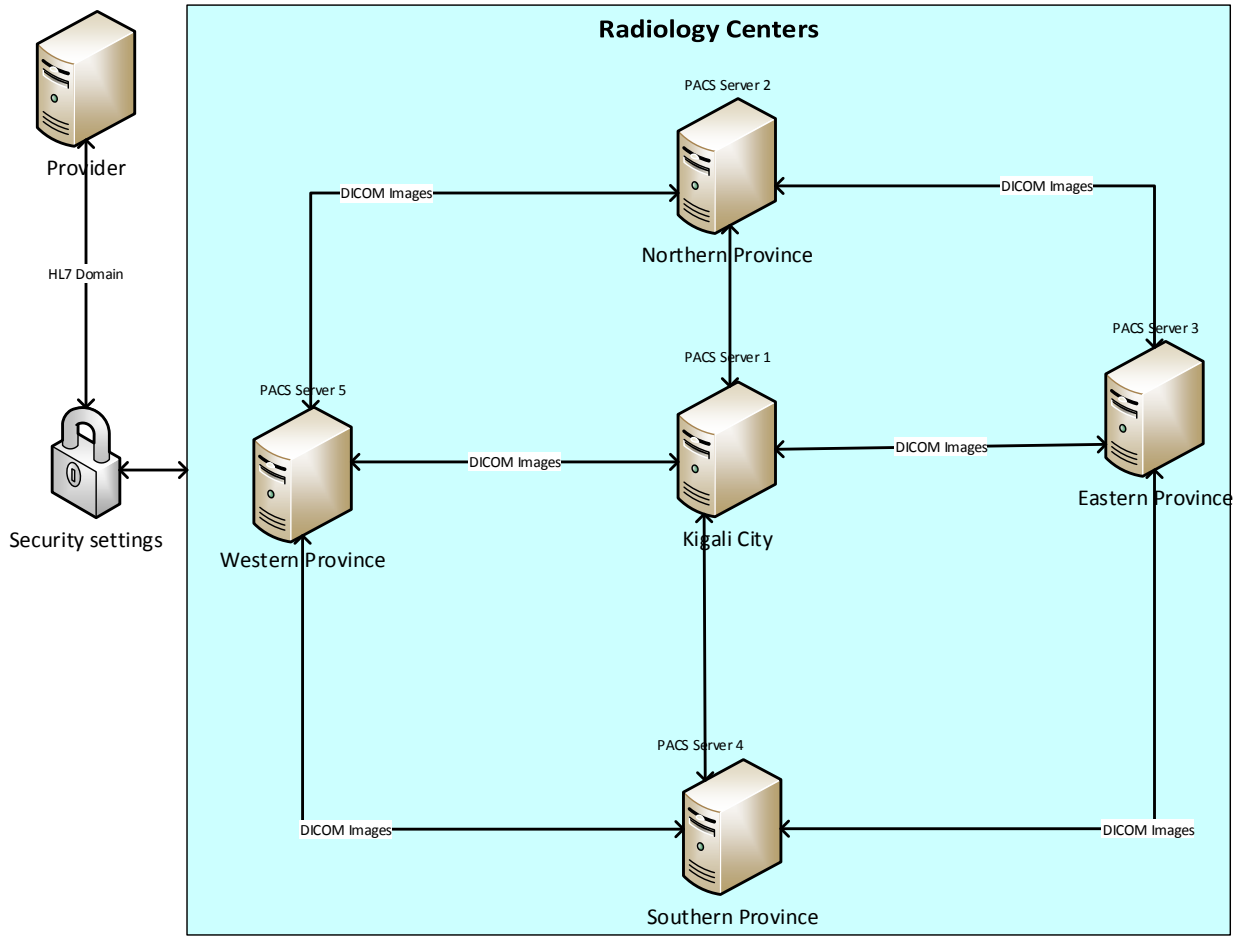


Figure 10: Five radiology centers across the country in four province and Kigali City.

Figure 11 shows the architecture of radiology setting in the hospital. The hospital has an EMR installed on the server. It shows separate servers one for the EMR and the other one for the RIS, however this setting can be modified as both systems can reside on the same server. This can depend on whether the systems have been supplied by the same or different vendors and the period of implementation. The purpose of linking the EMR and the RIS is to allow doctors to electronically place radiology orders through CPOE interface and receive results from radiologist in the EMR. For radiologist, the RIS improves the work by managing schedules, modalities worklist, image analysis and reporting.

As mentioned above, it is not easy to have a radiology with all necessary equipment in all hospitals in Rwanda. This is not only in developing countries but also in high income countries all hospitals don't necessarily have their own radiology. In some cases, universities can have radiology and they collaborate with hospitals for image analysis. For the case of Rwanda, the government is the main investor in health industry. So if five radiology centers are set with all necessary equipment, the hospitals can send their orders and receive analysis results promptly. The orders can be transmitted via internet which is the available resource in Rwanda. The connections have to be secured with VPN configurations and public key infrastructure (PKI). These five centers can serve as national radiology network. On the other hand, it is important to think about instant image traffics. One can suggest the synchronization off all servers once a day, specifically in the night, to avoid network congestion.

Figure 11 also shows two different domains: HL7 messages domain and DICOM domain. In HL7 domain, the systems communicate with HL7 messages. The EMR system serves as interface for doctors to enter orders and the RIS receives orders for completing tasks. Once the RIS received orders, it sends the order message to the PACS with all information about the patient and requested modalities. The radiology technicians can see the orders on the PACS workstations and they know which machine to complete the task. The radiology machines are directly connected to the PACS server, so DICOM images from these machines, are saved immediately on the PACS server. From the PACS server, the radiologist can analyze the image and write the report. The report goes with the DICOM image. The physician can receive the report by checking in their completed orders. The PACS server can be accessed through the separate web browser or within the same interface with the EMR. Some open source EMRs like Vista integrate a large number of systems such as media, but most others do not have such facility. In case of Rwanda, one can recommend separate web browsers as neither OpenMRS nor OpenClinic has media component at the moment.

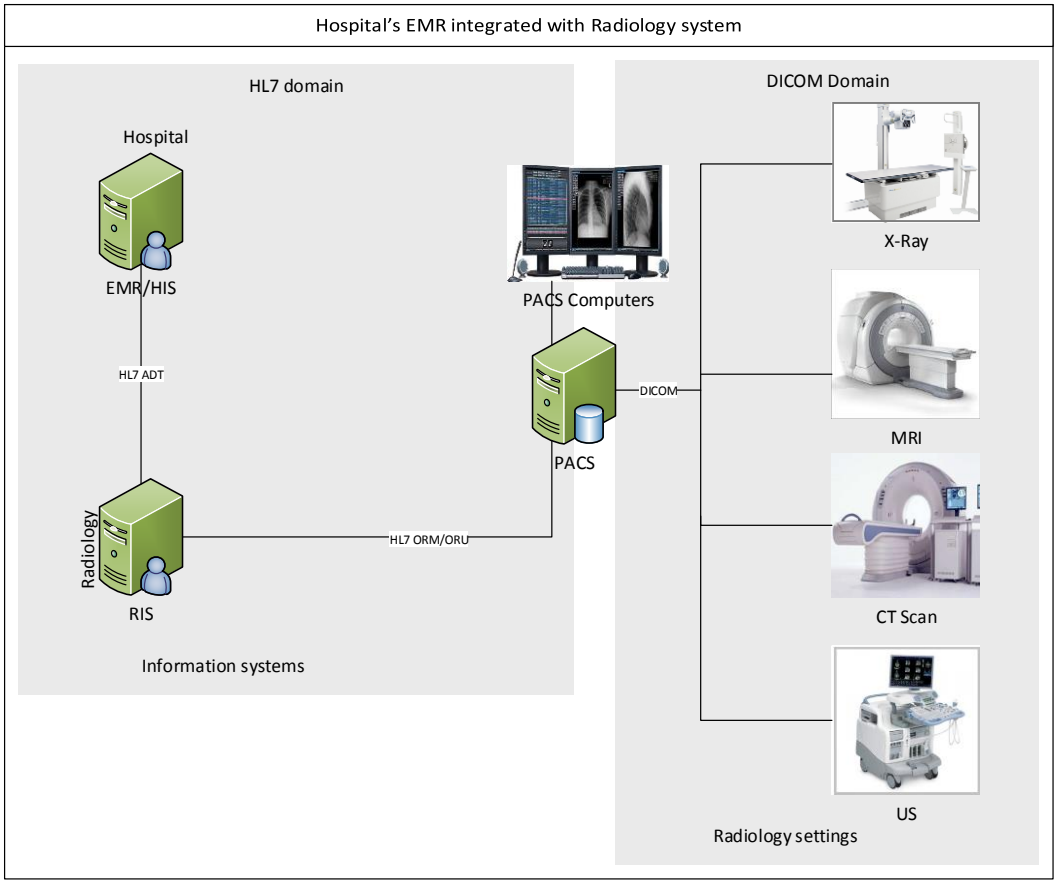


Figure 11: Radiology Architecture in the hospital, the integration of DICOM and HL7 domains.

ADT (Admission, Discharge and Transfer), ORM/ORU (Order Message/Observation Results Unsolicited), MRI (Magnetic Resonance Imaging), US (Ultra-Sound).

### 5.1.4 Pharmacy Information systems

In Rwanda, most of the pharmacies are private. There are pharmacies in hospitals and health centers, as well, but they are used by the patients who visit the healthcare facilities. All other pharmacies are private. These private pharmacies work with insurance companies under some specific agreements, to provide medicines to affiliate members. In the public sector there is an organization that has responsibility of supplying the public pharmacies with medicines. It is this organization that procures essential medicines for Rwanda. Private pharmacies can import other medicines which are not necessarily recommended by CAMERWA (Centrale d'Achats des Médicaments Essentiels Consommables et Equipements Medicaux du Rwanda), -the organization under the ministry of health that procure all medicines for public pharmacies.

There is a pharmacy information system that is used by this organization to manage the supply chain of medicines in public pharmacies. The district pharmacies, hospitals and health centers can order the needed medicines through Electronic Logistic Information Management System (e-LMS). However, the system is for supply chain only. This system cannot be linked with the electronic medical record system to enable the doctors to place the prescription for the patient in

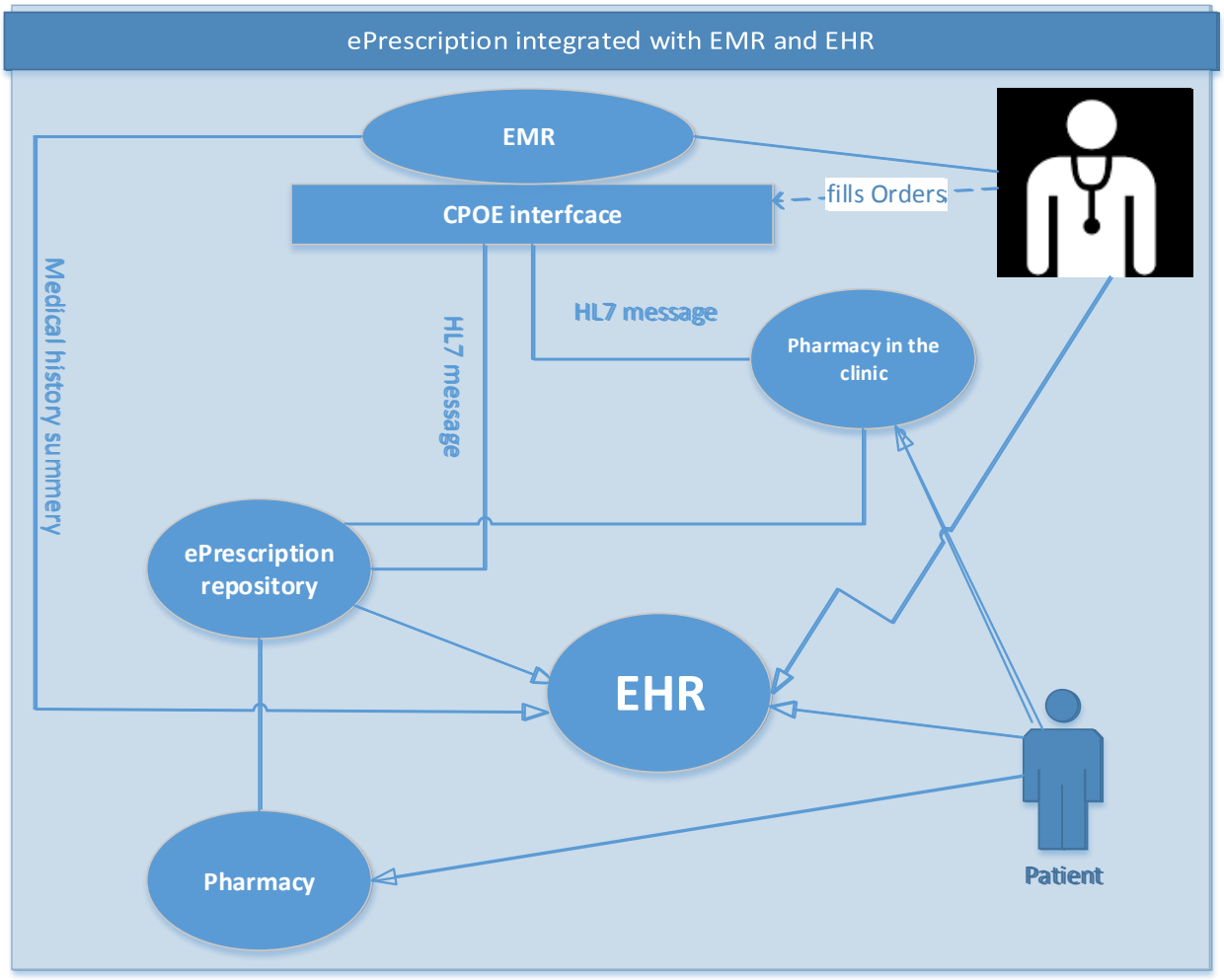


Figure 12: ePrescription system connecting healthcare providers with pharmacies

the system. The architecture suggests a plan for ePrescription. It is in that way, the public and private pharmacies can be connected to health providers to share prescriptions.

Figure 12 suggests the architecture of ePrescription and the information flow in the prescription process. With this architecture, the doctor electronically places medication orders in the pharmacy by passing through CPOE interface. The interface shows the current and previous medication for the particular patient. Through EMR, the pharmacist of the hospital dispenses drugs immediately to the patient or the patient goes to any pharmacy participating in ePrescription project. The order of medication is immediately uploaded into ePrescription repository. From the repository, all pharmacies can access the prescriptions by querying the patient by the national security number.

In Figure 12, ePrescription is linked with the EHR so that medications can be updated every time the medicines are issued to the patient. From the EHR, the healthcare professional can have the information about the previous medications for the particular patient.

### 5.1.5 Other Systems

Apart from the mentioned systems, there is a large number of other systems that might be integrated with NHIS. The health care delivery model is influenced by different stakeholders. The health insurance companies have considerable influence on the healthcare process and systems. Among the other partners in the healthcare system are government agencies and non-governmental organizations (NGO). All participants in the healthcare system of a country would have access to the NHIS. The system architecture views suggest every stakeholder's interest. Figure 12 is the example of the use case of the information flow between different stakeholders.

The public health systems are many and they are used differently. However, the MoH regulates public health systems and puts the effort for the harmonization of data collection, processing and the usage. Normally, public health organizations collect data from hospitals or health centers, however, rarely public organizations report back to hospitals about the health status in the community. With NHIS, public health professionals and doctors can communicate in both directions. The new communication way enables clinicians to have community health information. When clinicians have information about the health of the community, it can contribute in treating certain health conditions. Therefore, it is important to consider the interoperability between hospital EMR systems with public health systems. The use case on Figure 12 shows the information flow between patients, clinicians, and public health and insurance companies.

In Rwanda, there is a Health Management Information System (HMIS) used in public health. It is used to collect data from healthcare providers. This system is not connected with any EMR, however almost all district hospitals and some health centers have data managers who handle the task of data entry. With the implementation of nationwide EHR, the HMIS will have access to all needed information at central level. The necessary data can be retrieved from connected systems and EHR repository for different purposes such as researches, policy making, interventions and resources allocation.

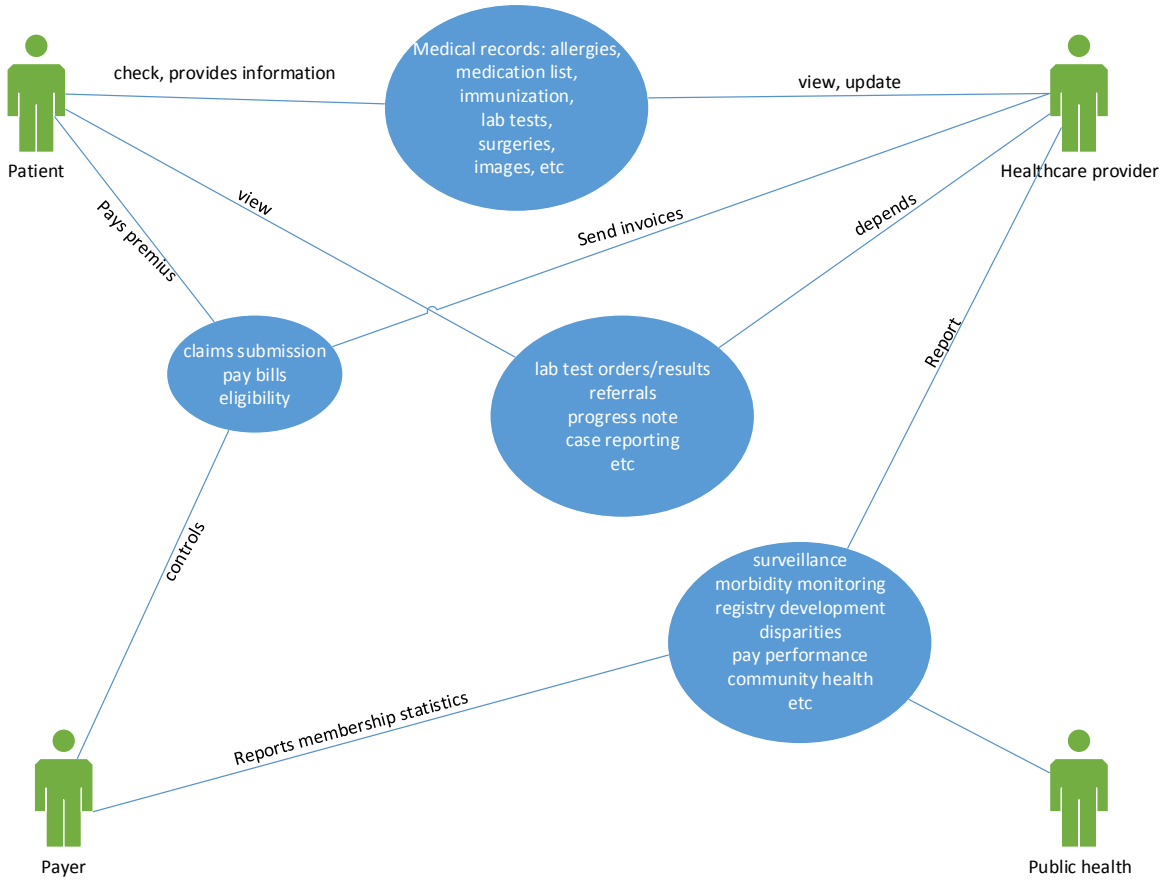


Figure 13: Use case of information flow between patient, healthcare provider, public health and payer.

The use case above gives the view of information that might interest each party. The patient, for example, can view his or her medical history, but he or she cannot update it, the health record is updated by a healthcare provider during the encounter with the patient. The payer or insurance company will control the eligibility, reimbursement, bills from healthcare organizations and report the membership to the public health organizations. The public health organizations might learn the ability of a citizen to pay healthcare services, disparities and coverage from insurance companies. Healthcare providers report to the public health organizations with different information such as morbidity, and new trends in clinical settings. The public health organizations can pay incentives based on performance to healthcare providers, and provide reports on community's health that might influence new models of treatment. Healthcare providers when treating the patient depend on previous lab tests, progress notes, referral messages, images and any other information related to the patient health that might be known.

### 5.1.6 Nationwide System Architecture

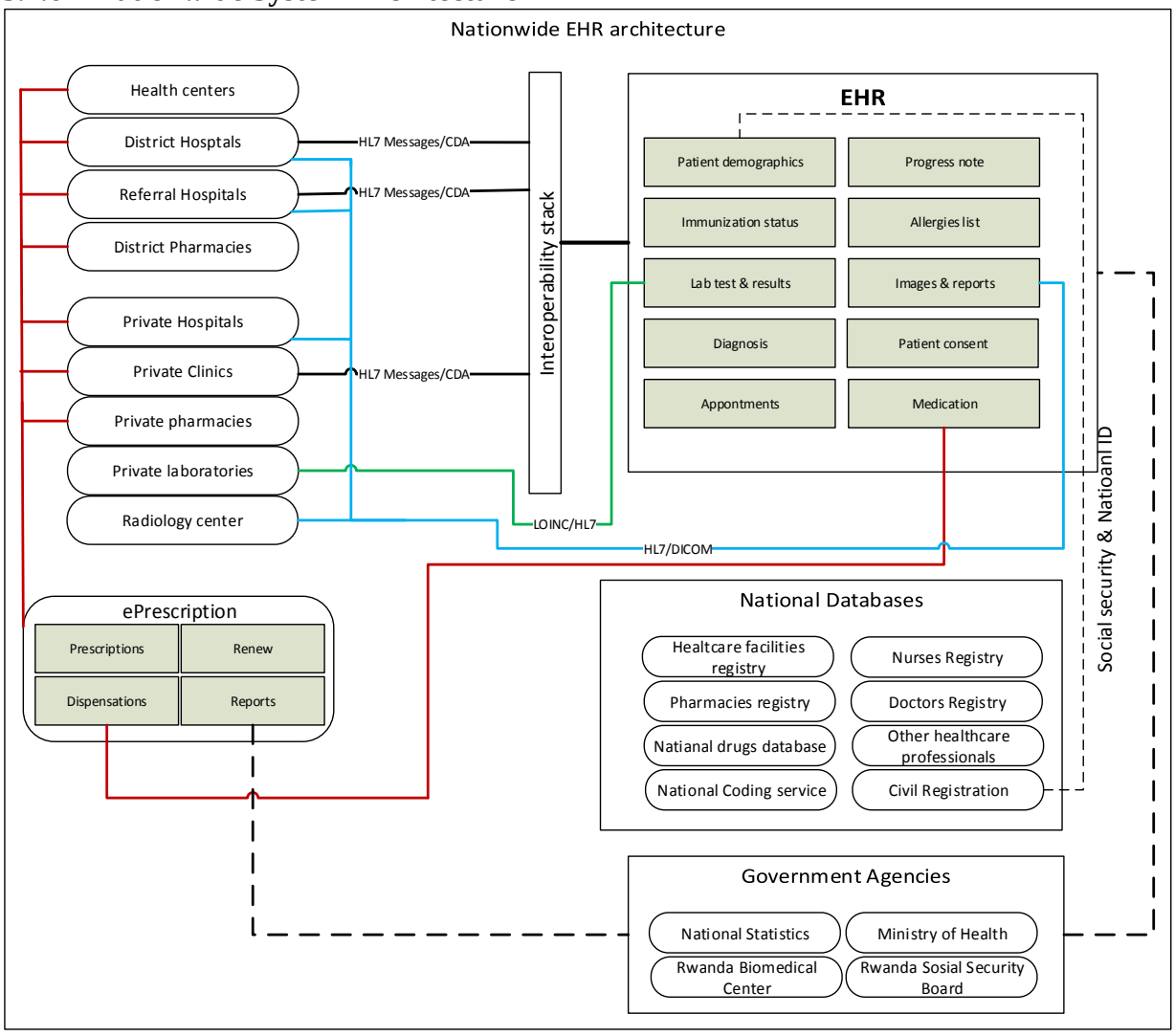


Figure 14: Rwanda Integrated National Health Information System Architecture

Figure 14 shows integrated systems that create the nationwide health information system. The foundation of the system is the availability of different systems implemented in different organizations that can be connected. Healthcare providers are key factors to accelerate nationwide EHR implementation. Therefore, implementation of at least minimally functional EMR systems in every health center and hospitals is the foundation of NHIS. The architecture above shows the need for the interoperability stack to enable every integrated system to exchange information with other systems of NHIS. The next chapter discuss the implementation of suggested architecture.

# 6. IMPLEMENTATION CONSIDERATIONS

The role of electronic health record systems, health information systems, nationwide EHR, standards and interoperability in healthcare systems have been covered in previous chapters. Chapter five focused on the architecture of an integrated national health information system for Rwanda. This chapter will cover the feasibility of the suggested architecture in Rwanda.

## 6.1 Healthcare organizations

The healthcare organizations in Rwanda are the hospitals, clinics and health centers. In all countries where they have developed a nationwide EHR, healthcare providers have been the starting point. The systems in healthcare providers are the most important systems that collect and process patient data, therefore most of the other systems get information collected in hospitals.

At the moment, Rwanda has three EMR systems in some healthcare providers. In reality, none of the hospitals in Rwanda is paperless. To start the implementation of the architecture on Figure 14 requires the implementation of EMR systems by healthcare providers. However, it is possible to start the implementation of a national EHR repository regardless the implementation of EMR systems in all health care facilities. In this way, healthcare providers with any EMR can upload patient information in that repository. This is the same as in many other countries where regional networks have been created before national networks. Thereafter, other healthcare providers will join the network after fulfilling the requirements. This is possible after fixing the unique patient identification issue.

## 6.2 Governance

The NHIS is a huge project that requires the commitment of a high level leadership of a country. In almost all countries which have implemented an integrated NHIS, the main player has been the government. In order to implement an integrated NHIS on the basis of the architecture in this thesis, the government of Rwanda will need to commit in the project by assuring the coordination and financing. The commitment of the government also ensures the elaboration of appropriate policies and regulations in order to support the implementation efficiently.

## 6.3 ICT Infrastructure

The system will use ICT infrastructure which is made of hardware, software and internet. Apart from the development of applications, a national health information system requires different ICT equipment. The basic networks in hospitals are already installed in Rwanda. However, their performance has not been evaluated in this thesis. The national EHR repository can be in the national data center. This can ensure the permanent electrical power and security. The healthcare providers have to connect to the national repository through VPN (virtual Private Network) and PKI (Public Key Infrastructure) has to be used to ensure the authenticity and integrity of exchanged messages.

In Rwanda, the electricity is still a scarce resource, it is not a problem that one can predict when it will be resolved. However, healthcare facilities have privilege of getting connections to the national power grid even though it is not permanent, sometimes the power cut off abruptly. It is important to install automatic generators and uninterrupted power supply (UPS) in order to avoid the power cut off in the middle of a transaction.

### 6.4 Security

In all countries where they implemented a NHIS, the data security and personal information privacy have been in several discussions. It took three years in Estonia to fix the issues of access control to the health information system. Apart from technological solutions, it was found that countries established policies that enforce data protection. One of the prominent components in security is people identification. In developed countries, they have developed personal unique identification models that are used to authenticate people accessing different services.

Unique patient identification helps to achieve a longitudinal record which is the purpose of a nationwide EHR. For example, countries like Denmark, Netherlands and Sweden issue national identification number at birth. This unique identification number is used in healthcare service to identify a person as well as in other public services. In Rwanda, there is a national identification number which is given to the citizen at the age of 16 years old. However, it is not used as identification in healthcare services. Apart from identification of people, the government has to establish clear policies about personal information protection.

To mitigate the data security in healthcare systems, Rwanda can give a unique identifier to the population at birth time. This can serve as an individual identification. On the other hand, healthcare professionals, pharmacists and all users of the system have to be registered in a particular database. The registration system should be able to assign roles to all professionals who use the system. Therefore, the role based access control will be the model to guarantee the access to users.

At the end, during the setting up all the required infrastructure, it is important to establish a disaster data recovery plan for the system. There are different possibilities to perform the backup, for example placing servers in different cities or outside the country. On the other hand, the disaster data recovery plan is a detailed document that determines the behavior of the organization during and after disaster. It is in this document that backups and their restoration policies are written. It should be prepared and written before the use of the system. Furthermore, the disaster data recovery plan has to be shared in among all users of the system.

### 6.5 Standards

The implementation of NHIS in nearly all countries which have already implemented it, has faced different challenges. Some of them may be specific for individual country and some are general for every implementation. One of the common challenges is to ensure the interoperability of the systems which must exchange the information. To overcome this challenge, all implementers have to follow international standards and guidelines. This thesis did not suggest any specific standards for software development or communication systems, however, one can find a large number of standards of such kind by contacting IEEE and IEC (International Electronical Commission) in collaboration with ISO standards. These SDOs develop different standards in the field of electronics and information technology. Apart from international standards in health IT, implementation of a NHIS requires the coding systems that support the consistence of exchanged messages. In the case of Rwanda, international standards that should be considered are: HL7 standards for the messaging and the information exchange between the systems, DICOM for

radiology systems and LOINC for laboratories. The coding system for diseases that is suitable for Rwanda is ICD10 which is provided by WHO free of charge.

### 6.6 Personnel development

The implementation of nationwide EHR is a process, not an event (Grant, 2010) and it requires different expertise. It is in this way that education and training will be a continuous process in different fields. Therefore Rwanda will need progressive human resource development to support the process and the maintenance of the NHIS. There are different domains of expertise to be strengthened with appropriate competent personnel. In developed countries, especially the USA and Europe, they have defined important domains in health IT and the required workforce. It can be a recommendation for developing country to try to fill up these areas of heath information technology:

- Direct Patient Care (DPC): This the area that includes nursing, medicine, allied health, etc.
- Administration: This area consists of health administration, finance, law, management revenue
- Information Technology/Engineering: This is the area for computer technology that is applied in healthcare services. It is generally filled with personnel with the computer sciences and engineering background.
- Informatics: This domain is normally confused with information technology/Engineering but here is difference between these domains. In informatics, there are different specialties such as clinical informatics, nursing informatics, health informatics and medical informatics. People with the medical background can fit this domain rather than pure computer engineers.
- Research/Biomedical: This area consists of biomedical researches and medical product development.

For the case of a developing country like Rwanda, it is obviously impossible to focus on developing these domains at once. On the other hand, it is also not wise to forget any of them. Rwanda will continue to educate and train medical staff in line with development. The administration domain has been considered in the educational system of Rwanda, therefore the workforce in this domain can easily found inside the country. The domain of Information Technology is not older than 20 years in Rwanda. Moreover, information technology is still new in healthcare service. Therefore, Rwanda needs to train more engineers especially in software development and information management. This goes to the domain of informatics which is also new in the healthcare services of Rwanda. The clinicians and other healthcare professionals consider this field as a computer domain. However, it is not easy for computer engineers to understand the need of the clinical domain. The development of the health IT solutions requires the participation of health professionals with additional IT understanding. These health professionals lead the validity of health IT solutions. They know better what healthcare providers need than computer engineers do. The key personnel for the implementation of NHIS for Rwanda are suggested the table 6

Table 6: The basic workforce

| Domain | Level | Number of personnel | Organization |
|---|---|---|---|
| Direct Patient Care | expert | 2 | e-Health department/Ministry of health |
| Administration | expert | 2 | Ministry of health |
| Information Technology/Engineering | expert | 2 | e-Health department/Ministry of health |
| | Basic | 45 | Hospitals |
| Informatics | intermediate | 3 | e-Health department/Ministry of health |
| Research/Biomedical | expert | 3 | Rwanda Biomedical Center |

The basic number of personnel who can coordinate the implementation of NHIS for Rwanda can be roughly estimated at 57 people with different expertise. The number is dominated by ICT workforce, however, the coordination should be assured by experts in the Ministry of health. Apart from the mentioned personnel, there should be a team working as a software company. This team may be hired as private company or created in the department of e-Health. It is the mobile team that does the actual implementation under the coordination the eHealth department.

In order to ensure the evolution and continuity of the system, it is recommended to offer different trainings in the domain of health IT in Rwanda. The training in ICT is available in schools of Rwanda, however, they should focus on new products development rather than implementation of existing systems. The other crucial domain is medical informatics. This domain needs more workforce in Rwanda.

## 7. CONCLUSIONS

This thesis focused on designing the architecture of a national health information system for Rwanda. To achieve this goal, the national health information systems in different countries have been explored. In addition, there was a visit to the health sector of Rwanda to observe existing ICT resources in that sector and in Rwanda generally. The objective was to design an architecture for a national health information system for a developing country. During the research, it was found that nearly all low income countries have not implemented an integrated NHIS. It is in this regard, this thesis focused also on finding other options for the health IT of the low income countries.

The studies on the different NHIS in the high income countries showed that the implementation of a nationwide health system requires many resources. It takes time for planning and implementation. It has been a long way since the 1960s when the first health information systems have been introduced in the hospitals. Since then, high income countries started to improve their health information systems. Therefore, nowadays most of these rich countries have connected their healthcare providers. On the other side, low income countries were not aware about these innovations but with the development of ICT, the technology reached everywhere. However, these systems are expensive for poor countries. Furthermore, there are limited infrastructures and required skills.

It has been found that nearly all the health IT initiatives in low income countries are mainly open source solutions. This is not the case in high income countries where they implemented proprietary solutions. The main cause of implementing open source in the health IT of low income countries is the lack of financial capability to purchase proprietary systems. However, this may be an opportunity for these countries to choose a limited number of systems and minimize interoperability issues. On the other hand, open source solutions support the skills development in these countries by allowing modification of the system for improvement. It is obvious that open source solutions in health IT will be continuously implemented in low income countries.

The architecture in this thesis is designed with the consideration of open source EHR solutions to be the backbone. However, it is not exclusively limited for the open source solutions, therefore it can integrate proprietary systems that follow implemented standards. At the moment, the EHR available in Rwanda can be improved to integrate all modules to accommodate all services of a hospital. This differs from high income countries where the hospitals have funds to buy complete solutions. Therefore, they can opt to buy the systems from different vendors. For Rwanda, the hospitals do not have such capability. This makes it easier for the eHealth department to provide one system for most of the public health facilities. This might be impossible if a hospital has its funds for buying its EMR system. The case of Rwanda is likely to be the same in most of the low income countries. Therefore, this architecture can be implemented in other developing countries. The implementation will depend also to the health system model. If the healthcare is dominated by the private sector, it might be challenging for building interoperable systems. It requires the effort of the government in the coordination.

The architecture in this thesis is simplified with basic components compared with architectures in developed countries. The basic components are the EMR systems of the healthcare providers.

Those systems, basically collect patient information during the patient's visit. It is the part of this information which is shared at the central repository. Other components such as national databases and other government agencies are static systems which query or supply the valuable information for healthcare providers. In addition, the social status component is not included in this architecture. On the other hand, the social status is always an important component in NHIS of high income countries.

The NHIS in high income countries uses a large number of standards and coding systems. In the developing countries, they will mostly use very common standards and preferably free coding systems. In this thesis, we have discussed about some standards and their roles in the health information system. However, some standards are recommended for the implementation of the NHIS for Rwanda. It is in this way that HL7 standards are preferred to support healthcare information exchange. For the laboratory, LOINC is used for laboratory measurement and laboratory orders management. Whilst, DICOM is used in for radiology imaging. All of these standards are used also in high income countries. For the disease coding systems, ICD10 is recommended for Rwanda and any other low income country. It is provided for free of charge by WHO, therefore, it will be the most implemented coding system in low income countries instead of the coding systems like SNOMED CT which costs the license fee for certain countries.

The advantage of this architecture for Rwanda is to give the big picture of the NHIS. With this architecture, the government can progressively invest in the health IT projects towards the fully integrated NHIS. By following the suggested architecture, the implementers will know at which phase they are. It is clear that the implementation of the EMR systems in health facilities is the first phase. It may be followed by e-Prescription implementation, then finally EHR repository. However, the unique identification of a patient is a crucial component of the system. The issue of identification is important in healthcare information exchange. The EHR system holds an individual health information from different healthcare organizations. Therefore the information is bound to the subject. The best way to recognize the owner of information is a unique identifier.

In addition, further studies on NHIS may help in finding out the details of every component of the architecture in this thesis. Furthermore, the prescription and nationwide EHR are not open source solutions. Therefore, the future researches can show the details of their functionalities. The other area to improve is related to policies and laws. The future studies can suggest the types of different policies and laws in the area of information management, particularly the laws on personal information management. Finally, the further studies can figure out the cost for the NHIS implementation. The cost may include the workforce and different assets.

In conclusion, this thesis provides an architecture of a National Health Information System (NHIS) for Rwanda. The architecture which is designed during the work of this thesis shows the big picture of the NHIS for Rwanda. It can be implemented in any other low income country preferably with small geographic size. In this way, the top-down approach can be used for leading the implementation. The basis of the architecture in this thesis is the combination of experiences from countries which have implemented NHIS and the existing resources in the health IT sector of Rwanda. This was the main goal of the thesis and it shows the success of this work. The

architecture in this thesis doesn't directly show the difference of it with other architectures existing in high income countries. However, this thesis suggests open source solutions in health IT as an alternative to implement an integrated national health information system.

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## APPENDIX A: Questionnaire used for the interview with in the eHealth department

1. What is the number of hospitals at different levels (referrals, district, public and private)? What about health centers?

2. What are health facilities connected to the internet (With fiber optic or other means?)

3. Is there any eHealth policy in Rwanda?

4. People identification (current situation & future plan). How people are identified in health sector?

5. How many hospitals with their own developed EMR and others with the one supplied by MoH (OpenMRS)?

6. What about Telemedicine? Is it currently working? How many hospitals have got infrastructures of this project? Any future plan? Any plan to expend telemedicine in all district hospitals if not yet?

7. Radiology systems. Is there anything happening in implementing any system of this type?

8. Laboratory systems, is there any connectivity between laboratories?

9. Pharmacies, Do you have any idea on how pharmacies are connected to hospitals? According to business model of Rwanda, do you think ePrescription is possible? Does MoH has plans of implementation of systems of such kind?

10. Who are potential stakeholders in eHealth (especially in EMR/EHR implementation)?

11. Is there any plan in coming years to implement any other type of EMR apart from OpenMRS which is in implantation currently?

12. What are criteria based on to choose OpenMRS rather than other open source EMR software?

13. Does eHealth department has some influence in private hospitals on IT solutions implementation?

14. Any additional information related on health IT in Rwanda?