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Strengthening community health management systems using real-time reporting tools in Rwanda: Improving Malaria eradication through RapidPro

By

Name: Emmanuel MANIZABAYO

Registration Number: 218015654

A dissertation submitted in partial fulfillment of the requirement for the degree of

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(Option: Internet Technology)

In the College of Science and Technology

Supervisors: Dr. Said NGOGA RUTABAYIRO

Dr. Didacienne MUKANYIRIGIRA

March 2021

DECLARATION

I declare that, this project entitled, "Strengthening community health management systems using real-time reporting tools in Rwanda: Improving Malaria eradication through RapidPro" is original and has never been submitted to any University or other Institution of Higher Learning. It is my own research whereby other scholar's writings were cited and referenced. I thus, declare this work is mine and were completed successfully under the supervision of Dr. Said RUTABAYIRO NGOGA.

Emmanuel MANIZABAYO

218015654

Signature: …………..........

Date: ………………………

CERTIFICATE

This is to certify that the project work entitled "**Strengthening community health management systems using real-time reporting tools in Rwanda: Improving Malaria eradication through RapidPro**" is the record of my original work done by Emmanuel MANIZABAYO with Reg no: 218015654 in partial fulfilment of the requirements for the award of Master of Science in Information Systems of College of Science and Technology, University of Rwanda during the academic year 2020.

Supervisors

Dr. Said RUTABAYIRO NGOGA	Dr. Didacienne MUKANYIRIGIRA
Signature:	Signature: ....
Date:	Date: ....

HoD of Information Systems

John MUNYAKAYANZA

Signature: ....

Date: ....

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LIST OF SYMBOLS AND ACRONYMS

A2P: Application to Person

API: Application Programming Interface

AWS: Amazon Webservices

CHW: Community Health Workers

COVID-19: Coronavirus Disease of 2019

DevOps: Development and Operation

DHS 2: District Health Software version 2

DSR: Design Science Research

ELK: Elasticsearch, Logstash and Kibana

FaaS: Function as a Service

GSM: Global Service Mobile

HTTP: Hypertext Transfer Protocol

ICT: Information and Communication Technology

IDSR: Integrated Disease Surveillance and Response

IHSSP: Integrated Health System Strengthening Project

ML: Machine Learning

MoH: Ministry of Health

P2A: Person to Application

R-HMIS: Rwanda Health Management Information system

RBC: Rwanda Biomedical Center

RISA: Rwanda Information Society Authority

SaaS: Software as a Service

SMS: Short Message Services

UNICEF: United Nations Children Fund

VPC: Virtual Private Cloud

WHO: World Health Organization

Abstract

Efficient communication and collaboration are the major stages in tackling infections particularly those which need a fast response based on real-time data. The fast growing of mobile phone usage has played a key role in managing different diseases by providing real-time data and their availability on time to the end users. Different solutions have been adopted to minimize the effects caused by diseases and gain a considerable control of them through the usage of different mobile phone applications and the instant messaging applications.

Malaria is one of those diseases that need a joint and effective communication of all government and private entities that involves in providing healthcare services and decisions that are linked to healthcare sector and diseases management. Despite the measure efforts in reducing new malaria cases, malaria remains a challenge in the sub-Saharan countries with a higher percentage of morbidity and mortality.

Many efforts and studies have been carried out on malaria eradication to evaluate the improvement brought by Information and Communication Technology (ICT) in maximizing the surveillance and monitoring of its prevalence, however, few studies have been focused on the patient centric approach in providing the required information in real time. Real time reporting and monitoring of malaria cases is a crucial domain that need to be addressed in depth with time, location and completeness.

This research thesis will firstly evaluate the existing malaria surveillance system and its model in the reduction of malaria prevalence using RapidSMS as the first tool applied on malaria control and elimination in Rwanda. Secondly RapidPro will be used to improve the existing malaria surveillance system model in designing new malaria surveillance system model with patient centric approach. Finally, it will compare the existing malaria surveillance system model and the new designed surveillance system model to enhance the existing data flow model in fighting against malaria in Rwanda.

Keywords: Malaria, RapidSMS, RapidPro, Surveillance system

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Introduction

Malaria is one among the most challenging problematic around world especially in Africa sub-Saharan region. It is the tropical and subtropical disease where 3.4 billion people within ninety-two (92) countries and territories worldwide are at risk of being infected and develop a disease and 1.1 billion are at higher risk where more than one person has a risk of being infected by malaria within a year. In 2018, malaria cases were estimated to 228 million globally with 93% of incidence based in Africa sub-Saharan region followed by South-East Asia with 3.4% incidence and Eastern Mediterranean with 2.1% incidence (WHO, 2019).

The global reduction of malaria has reached a decrease of 18% incidence between 2010 and 2017 and the mortality rate also reached 28% worldwide. The number of deaths still higher wherein 2010, malaria has recorded 435,000 deaths globally with Africa representing 93% where 61% are the children under 5 years old and only in 2018 the death of children under 5 years old encounter 67% of all the fatalities.

Malaria in pregnancy compromises the life of a mother and the fetus where in 2018, 11 million women were infected by malaria and consequently 900,000 died. The proportion of maternal to neonatal also accounts from 10,000 to 200,000 per year (Julianna Schantz-Dunn, 2009) in malaria deaths. Unlike global prevalence, Malaria in Rwanda is also a heavy burden which need a two-way measure at all levels with a prevalence that range from the urban area to the rural area.

The number of individual tested positive differ from the children under five years, women and the adults where malaria in children varies from 13% in rural area to 3% in urban area. The prevalence of malaria in women varies also with educational background where it fluctuates from 6% in women with no education to 3% in those with higher education. In Rwanda, malaria prevalence also varies within the provinces in which the eastern province comprises the higher range of 17% which is nearly the global incidence and the north province with 1% and the overall prevalence upsurges to 7% in the whole country (RBC, 2017) (MoH, 2019).

The surveillance system of malaria is the key feature in the way towards malaria control and elimination. The system to play this role should be robust, efficiency and responsive enough to be able to tackle all the meadows and sectors involves in the investigation and response providers.

The ideal surveillance system of malaria should have different components including automated data analysis, rapid data collection, reporting, data storage and management and the collection of feedbacks with the specific responses to the targeted groups or users. To design this system, the data analysis, collection and output should address in real time with the accurate information that will lead to a rapid response of the current presented cases (chard G A Feachem, 2012).

1.2 Background and Motivation

Malaria surveillance is grouped into different types with reference to the surveillance phase in which a country is within respect to the World Health Organization guidelines. The surveillance systems depend on two factors such as the level of malaria transmission and the resources availability to conduct a surveillance. It is conducted in four different stages, elimination, high and moderate, low and very low settings (WHO, 2012).

The high and moderate transmission is characterized by the concentration of malaria cases, higher deaths of children under 5 years old and a considerable effect of malaria on the pregnant women. The number of outpatients is also increased in the high and moderate transmission with a high concentration of plasmodium falciparum as the main malaria transmission specie (Ruth A. Ashton, 2020).

The low transmission is characterized by a low number of transmission and it is distributed in the people of all age. The percentage of mortality is very low and most the presented cases are imported from outside of the country of reference (WHO, 2014). The surveillance of malaria is critical in the initial phase for the reduction of the malaria cases and tracking their impact within the community.

The surveillance should be based on the quality data that are sent though different channels of communications especially the health facility on timely manner, accurate and completeness. The quality of surveillance will also depend on updating the stored information and the maintainability of the existing data to ensure the quality of resources distribution (Kimberly E. Mace, 2015).

1.3 Problem Statement

Malaria surveillance collects relevant data systematically and consolidate the information from them which deliver rapidly the decisions towards the action to prevent and control malaria. The surveillance provides timely malaria information at national scale or a specific district. The main objectives of the surveillance are planning, contribute, alert, describe, evaluate, hypothesize and research to acquire knowledge and track the way forward to tackle the effect of malaria in the community.

This research thesis will evaluate the existing malaria surveillance models in reduction of malaria prevalence using RapidSMS as the first tool applied in malaria control and elimination in Rwanda since 2018. Secondly RapidPro will be used to validate the functionalities of the existing model and design a new model with patient centric approach. Finally, it will compare the existing malaria surveillance model and a new designed model to enhance the information flows in fighting against malaria in Rwanda based on real time data.

1.4 Study Objectives

1.4.1 General Objectives

The general objective of this research thesis is to develop a new model with in depth data analysis in real time to optimize the surveillance of malaria incidence in Rwanda.

1.4.2 Specific Objectives

- To analyze the performance of existing malaria surveillance flow model designed using RapidSMS.
- To improve the existing model using RapidPro as an optimized RapidSMS tool in designing surveillance especially in health sector.
- To develop a new model that will improve the surveillance of malaria in Rwanda with patient centric approach.

1.5 Methodological framework

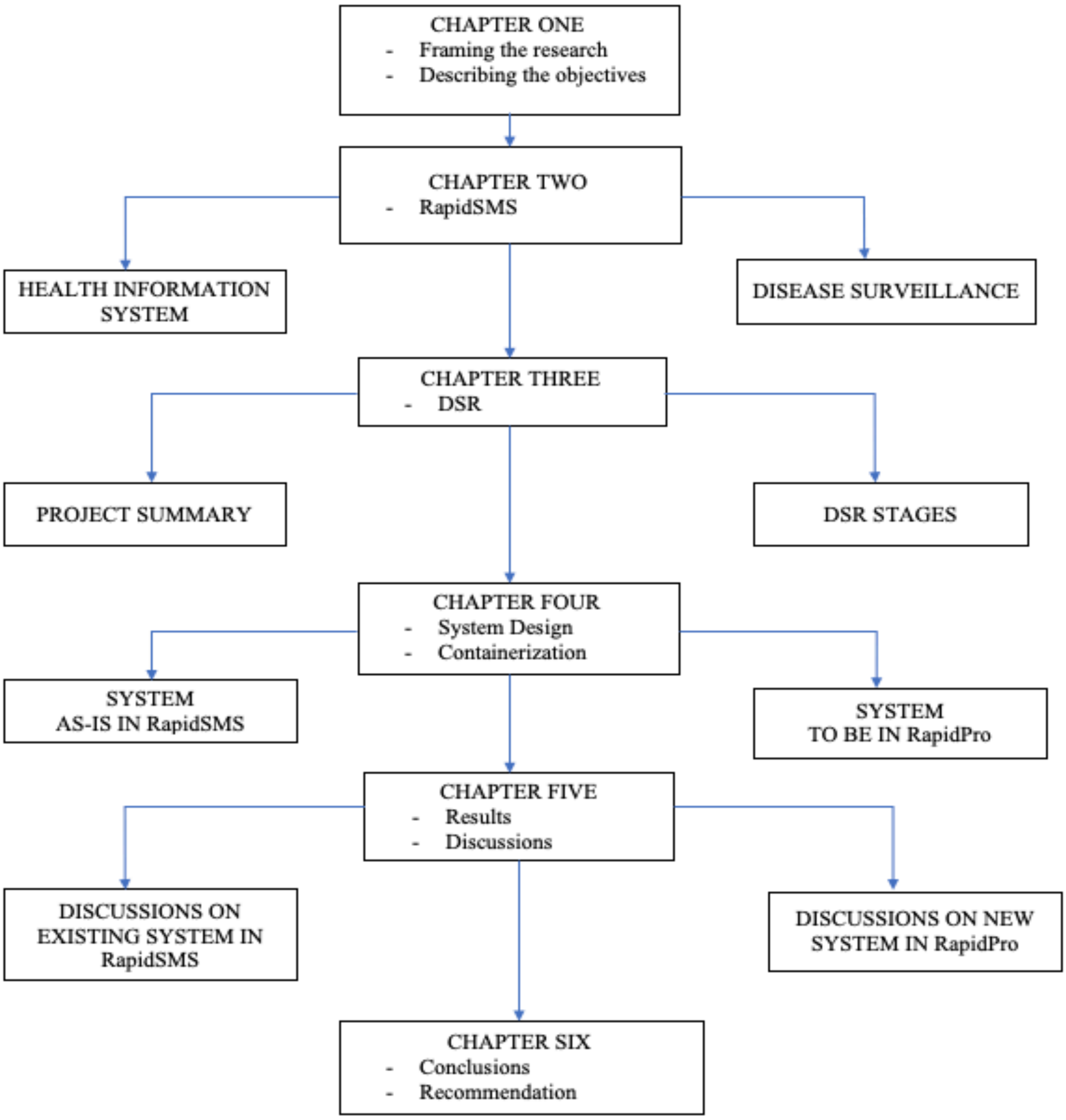


Figure 1:Project Roadmap

1.6 Hypothesis

A data centric approach in the surveillance of malaria is the main approach in tracking of the control and prevention progress towards malaria elimination in Rwanda. The research under this study is aimed at testing the following hypothesis on how Rwanda can "**Strengthen its community health management systems using real-time reporting tools in improving malaria eradication through RapidPro**". Different tools and application will be used to prove the above hypothesis and its verification basing on the accurate data and their implication in the surveillance of malaria.

1.7 Scope of the study

This research is limited on the surveillance of malaria incidence in Rwanda with the timeframe of three years. Malaria surveillance using RapidSMS was started in 2018 as a tool developed to accommodate malaria surveillance data. The system was developed to address the problem of timely reporting of severe malaria and stock out in Rwanda. Despite the rollout of the system, it was not adopted at scale with other module that are required to be included in the system.

In this regard, RapidPro was used to scale up the functionalities of the existing system and increase the level of adoption and the usability of RapidSMS based system. This research thesis will develop a system model to automate the surveillance of malaria reporting with real time data and their analysis to track the achievement and control in Rwanda.

1.8 Significance of the study

Malaria surveillance using real-time data is the fundamental intervention in obtaining the accurate information on the progress of malaria control and prevention. The context of possessing the real time data and tracking the progress based on real time solution can enhance malaria control and prevention in strengthening the decision making based on the actual data available (Sanie S. S. Sesay, 2017). The specification of the collected data within a specific area provides also a useful information in a that area not only on the decision's makers but also on the management of resources required to intervene on time to reach surveillance targets.

Different real time data analytics tools are also the major benefits which arisen in the real time data generation and monitoring especially in big data modeling environment (Ashwin Belle, 2015). The outputs of this research will be a new malaria surveillance model designed in RapidPro to collect malaria cases from the village level using community health workers. The new model will enable the health authorities to send and receive notification from the community health workers level hence detecting malaria cases status on time.

The output of this research will also improve the way of sharing the required resources to mitigate malaria cases with accurate information from community health workers. The data collected from community will reach the policy makers within a considerable time for the intervention. This research will also help the ministry and the respected agencies to track the progress in fighting against malaria and to detect the district with a lower progress within time and allocate the required resources on time.

1.9 Organization of the study

This research thesis is organized into six chapters which are organized as follows, the first chapter gives an introduction which contains the project objectives, scope of the study, problem statement, background and motivation, hypothesis, significance of the study and organization of the study. The literature review is provided in the second chapter. The third chapter provides the research methodology.

The fourth chapter provides the system design, analysis and the system security. The testing results are provided in chapter five for feasibility of the application using the available user case model in RapidPro. The chapter 6 gives the conclusion, recommendation and the future work.

1.10 Conclusion

To validate the application and its usability, the new designed model in RapidPro will be tested against the current data used in designing COVID-19 flow. This research thesis will foster a system to collect and analyze the obtained data in a real time using Elastic stack as a big data tool to analyze real time data and generate the dashboard using Kibana. The results will be displayed on a dashboard to be visualized by the decision makers and adapt to the changes within the presented data in a format of the malaria cases management and its reduction in Rwanda.

CHAPTER TWO: LITERATURE REVIEW

2.1. Information systems

Information systems is the combination of people, processes and technology that are grouped together to address a given issue in society. The people in the information system also called actors played a role of interacting and usage of the system in place whereby they exploited the processes in place to solve the actual issue. The processes are the goal-oriented activities that run in the background in the request of information to solve the presented issue. Technology is constituted of the hardware, software used to process the activity requested (Robin, 2011). The information system has the role of reducing the healthcare cost and increase the outcomes of healthcare services.

2.2. Information systems design for disease control and surveillance

The information systems designed for disease control should tackle different domains to be able to address the population health trepidations. The domain to design an information system is distributed into different determinants such as environmental, biology and genetics, individual behaviors, social, economic and demographic. The goal of policy makers is to use the available information from the community feedbacks in addressing the existing setback and planning for the future ahead in avoiding health misadventure in the community (WHO, 2008).

The data collected from the community play a big role in feeding the health information system where the useful information is extracted to be shared with the decision makers. From the decision makers, the information and the decisions are shared to the institutions in charge of delivering the services for the implementation and their services alignment to the decisions in place. The services delivered to the community are rated with the degree of satisfaction and the feedbacks are shared again to the health information system for review and adjust to fit within the context of community (Osman, 2011).

The required resources are also allocated using the feedbacks collected from the community which should reflect the level at which the health service was delivered, the health equity and the satisfaction of the acquired services within the institutions in charge of delivering the services. The usage of the accurate information from both the community and the institutions delivering the services helps in disease control and management in timely manner and the rate of spread can also reduce using a well-designed information system (Neale Smith, 2013).

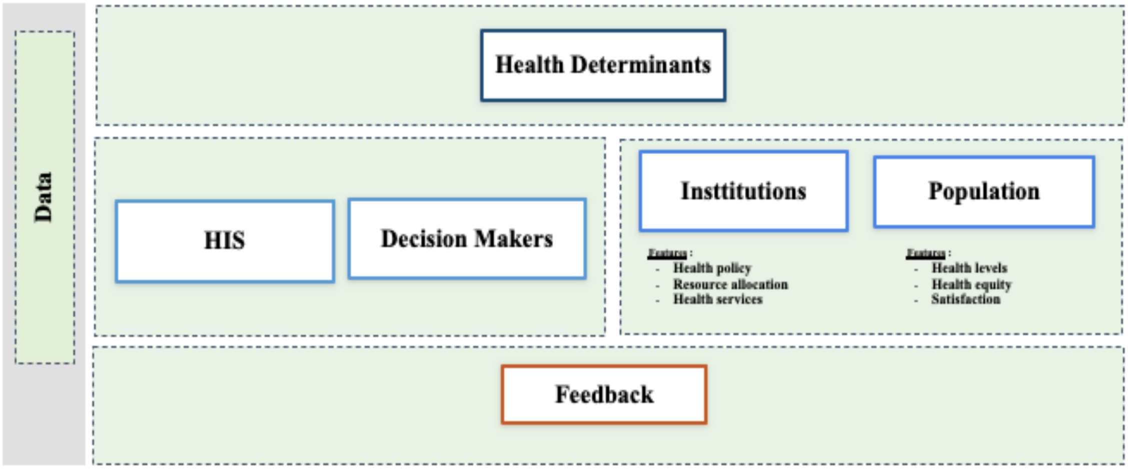


Figure 2: HIS Pathways for data collection and feedback

2.3.Health information systems Structure

The health information system is based on the data collected from different community within a country. To be able to analyze the acquired data, the obtained datasets should be coded, processed, stored and distributed according to the World Health Organization standards for health data management. Figure 2 shows the steps used to collect, process, store and distribute the collected data.

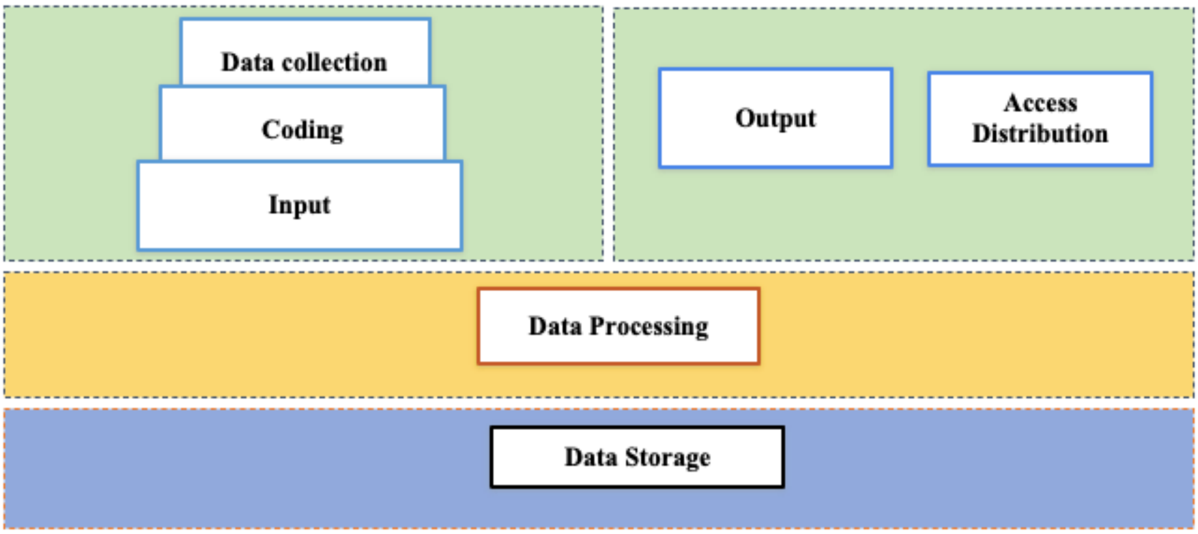


Figure 3: Health Information Systems stages

The surveillance of diseases in Rwanda has different reporting systems such as Integrated Disease Surveillance and Response (IDSR). The IDSR in Rwanda started in 1998 with the purpose of reducing the national communicable diseases and the enhancement of reporting and data driven decision in health sector. It presented different challenges such as the limited resources, insufficient staffs and low resources buy in with the country (Ibrahima Socé Fall, 2019).

The DHIS 2 was also deployed to assist in the visualization of the collected data because it has a web interface and the capability to create graph for a specific health facility within a specific disease (evaluation, 2017). The usage of RapidSMS in Rwanda to collect the real time severe malaria cases and the stock out notification have also increased and scale up the malaria eradication and boost the way of utilization of malaria drugs stock in the community through the community health workers (CHWs) (Huddleston, 2013).

All those open-source software's above was used to mitigate the inconsistence in the data collected and the decisions taken based on the presented data because there was a delay in receiving data where the data was recorded on the paper-based systems.

2.4.Digital health for diseases control and monitoring.

The term digital health is used to describe the utilization of information and communication technology (ICT) also known as digital technologies in achieving health financing and programming. The main objective of digital health is to achieve an improved well-being of population through the usage of digital devices such mobile phone, wireless communication and their combination to mitigate the effects of diseases. The utilization of digital technologies has improved the service utilization, reducing stock out and enhance quality of care (Unicef, 2015).

2.5.Health information systems in Rwanda

The coordination of health information system in Rwanda was started in 2009 with the launch of Integrated Health System Strengthening Project (IHSSP). The health information system before 2009 was distribute to the extent that the health personnel have to store the data in the local database and export that data on a portable flash drive. The exported data have to be sent to the district level for the synchronization with the other data exported in different health facilities within a same district.

The district level has to compile the obtained data from different health facilities and export the compiled data to the flash drive to be sent to the central level. The process was time consuming and not cost effective to the point that the data exported were not useful in improving health policies and strategic planning to global health development (MoH, 2014).

The launch of R-HMIS in 2012 brought additional features to the existing information systems whereby the first one was designed only to collect data from the health facilities around the country. The development of R-HMIS using DHIS 2 which was a web-based software, customizable and free has more advantages to the existing data with the easiest way to create a report at the health center level. The health centers also can create the visualization of their data within a time (DHIS2, 2020).

The complexity of health systems has enforced the developers and the organizations to embrace the utilization of open-source software. The open-source software has the advantages of reducing the cost and the time for development of a health solution. Despite the advantages of open-source software, it also presents different drawbacks that can hinder its utilization such as security, commercialization and license (Gunther Eysenbach, 2017).

2.6. Digital tools for malaria control and surveillance.

2.6.1. RapidSMS

RapidSMS is a free and open-source software developed in python and Django. It was expanded and customized in Rwanda to be able to store the data collected by the community health workers in the country. The usage of RapidSMS software was started in 2009 with a piloting phase in Musanze district where it was designed for maternal and child health surveillance.

The maternal and child health surveillance has been scaling up national wide in the reduction of mother and child death. The adoption of RapidSMS have increased the births taking place in health facility and reduced the numbers of death and complications during the child birth. The deployment of RapidSMS system also have improved the maternal based decisions making through the real time data collected from the community health workers in each and every village in the country (Hinda Ruton, 2016).

2.6.2. RapidSMS architecture.

RapidSMS is divided into three main components such as the applications, backend and router. The applications are the components in charge of performing the business logic, to handle and respond to the messages, extended the data model and create the web interface with Django views and templates. The backend plays a role of delivering the messages to the external sources such as GSM modem and Twilio over HTTP protocol (RapidSMS, 2013).

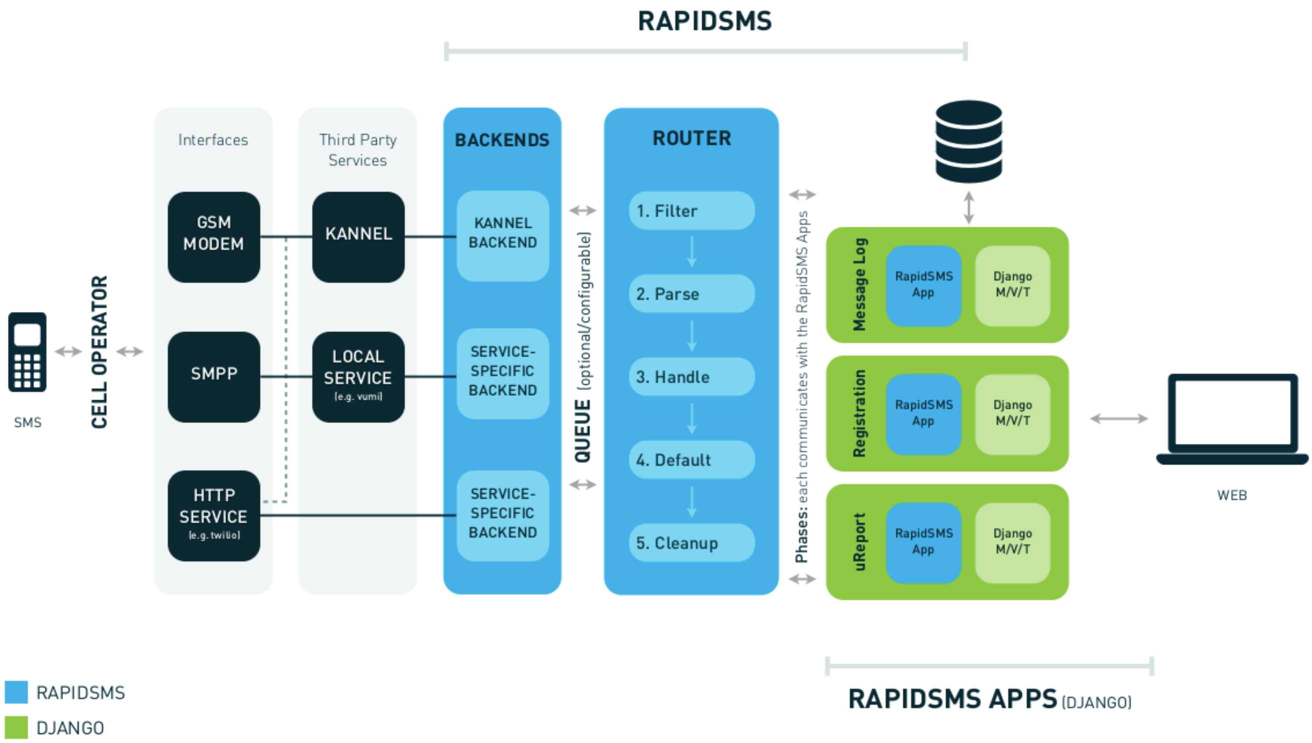


Figure 4: RapidSMS components architecture.

The router is the component in charge of binding the RapidSMS applications to the respective backend component. It also provides the infrastructure to receive the incoming messages and sending the outgoing messages within a given application.

2.6.3. Malaria surveillance using RapidSMS in Rwanda

The RapidSMS for malaria surveillance system was introduced in 2018 for severe malaria and stock out notification. The system was designed in framework of reducing severe malaria cases and tackle them in community within a shortest time frame and avoid the early death of the parson infected. The community health workers acquire the mobile phone that have been used to address the maternal and child health, the tuberculosis both using RapidSMS.

2.6.4. Severe malaria and stock out notification system

The information sent by the community health worker is received by the central server on the ministry of health. The automatic feedback will be delivered to the community health work that the message was received successfully. The message sent by CHW is also shared by the nearest health center, the district hospital, the ministry of health and the ambulance services once the patient is in critical condition.

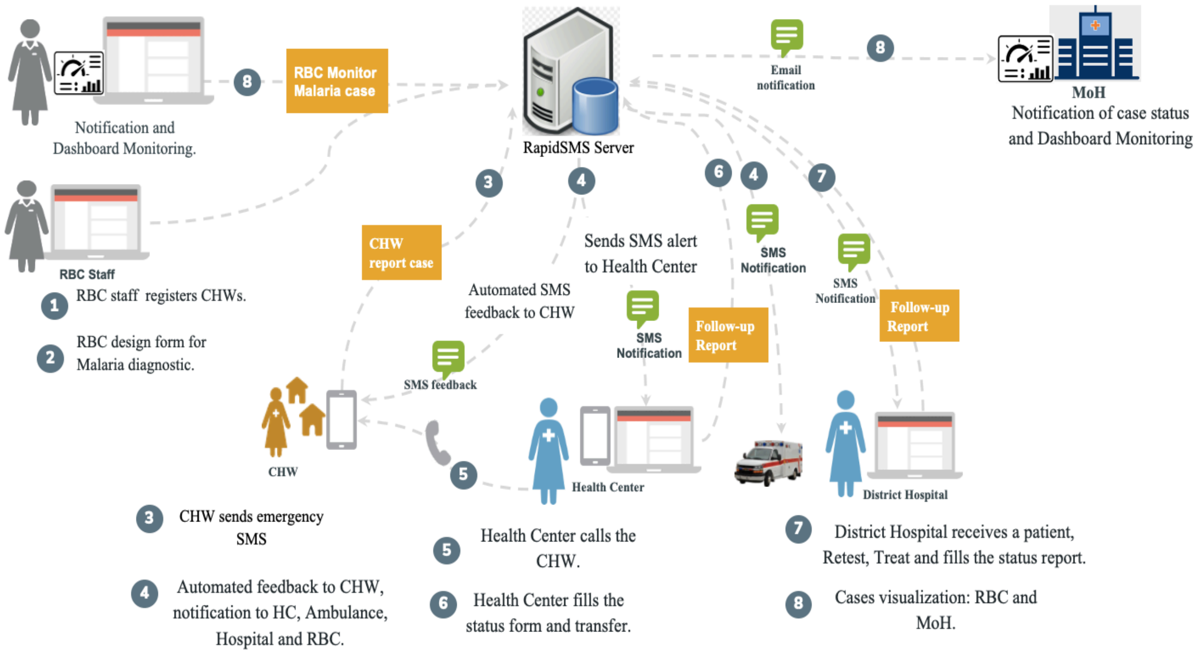


Figure 5: RapidSMS based malaria surveillance system workflow

The system was implemented to reduce the delay in the transfer of severe malaria patient in order to avoid the complication of the disease that led to the death of the patient.

2.6.5. Channels in RapidSMS.

RapidSMS application uses SMS message as a channel to communicate to the Community Health Workers (CHWs) in the reporting of malaria cases. The usage of SMS channel has been shown an effective way of communication especially in the area of health (Kew, 2010). The timely and accurate dataset can be obtained through the best practice of designing a structured text messages that reflect the researchers and medical workers solution.

The text messages should also address the problem of missing data where the participant with an invalid answer while reporting will receive a reminder to t send the valid response (Noa'a Shimoni, 2020). After reaching its saturation point in 2012 with about 8 trillion, the SMS users have been decreased continually with the introduction of the smartphones. The smartphones come up with the introduction of application to person messaging (A2P).

The incorporation and adoption of smartphone has also introduced the new way of messaging using the A2P applications such as WhatsApp, Facebook and Telegram. With the saturation point of SMS messaging and using it in RapidSMS as channel of communication, it limits the way of communication to the ender user especially the community health workers (kirusa, 2019).

2.6.6. RapidSMS system limitation

The effective response to severe malaria notification depends on the SMS sent from the CHW and received by the in charge of Community Health Worker and the Titulaire of the nearest health center. The SMS is also forwarded to the district hospital with the notification to the director of clinical services, chef nursing and the logistic. This gives RapidSMS notification system a single point of failure once the mobile phone or the person in charge of receiving the notification is not available for a direct response.

The patient information recorded in the Community Health Worker register are not shared in the SMS sent from the CHW to the nearest health center and the district hospital. This creates much repetition in patient records which increase the delays in the patient treatment at both the health center and the district hospital.

The health centers are still using the paper-based system which also hinder the usage of the RapidSMS notification system since the person in charge of capturing the patient information have to fill both the paper-based registers and the web-based RapidSMS notification system which turns to be a dual work to the person in charge at the health center.

The RapidSMS notification system only use a single notification channel which is an SMS, the mobile phone SMS has a limit of 160 words which also limit the incorporation of all patient information from the CHW. This also makes the person in charge at the health center (Titulaire and the in charge of CHWs) to use the phone call for more information on the patient including the information that are not recorded in the SMS notification.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. Project summary

This research thesis pacts with the modeling and improvement of malaria eradication model with data centric approach in Rwanda. It is composed of system model development, alpha testing and technical characteristic of malaria eradication system in the way towards confronting malaria infections and reduction in Rwanda. The system is modeled and integrated in RapidPro application which is a World Health Organization application developed by Nyaruka to address the shortage of health information systems around the world.

The evolution of RapidPro started with the deployment of its first version in 2014 when UNICEF partnered with Nyaruka, a software firm based in Rwanda to open source their application called Textit and then give it the name of RapidPro. RapidPro is an interactive application which was built to adapt to different contexts especially digitalizing of health sector data and timely response. This project started in August, 2019 with the survey on digital health tools that can be used to implement a responsive system in addressing malaria infections and eradication in Rwanda based on data driven decisions using community health workers (CHWs) data from all villages around the country.

In this period of survey which started from August, 2019 to October, 2019, RapidSMS application was tested to see if its functionalities can be used to expand its coverage in modeling malaria eradication system as it was being used in maternal health in the country. From testing RapidSMS and its functionalities, we found that this application has reached its end and it is no longer supported by the World Health Organization (WHO) because its expansion to cover other diseases need different approach including the hardcoding of the component to be expanded.

From November, 2019, the survey continued to find out the open-source application that can be used to model malaria surveillance system in Rwanda hence RapidPro was discovered. RapidPro application is developed in python and Django where it is composed of seven components with RapidPro as the main component Mailroom, indexer, archiver, courier and two mobile applications for message relaying and offline data collection.

The sustainability of the deployment of the application depends on the application packaging, then we adopted the cloud computing application development. The deployment of application in cloud follows the directive of application containerization where the application is packaged in a small unity called containers and reached as a single service running as a microservice.

From January, 2020 to August, 2020, we followed different training on the deployment of a containerized applications and the application deployment standardization in cloud computing including one that took place in Rwanda Information Society Authority (RISA) starting from 1st to 12th March, 2020. The trainings on the application containerization were in line with building RapidPro containers for its deployment in Amazon Web Services and Google cloud.

The emergency of COVID-19 pandemic started from March, 2020 has hampered our plan for performing beta testing before the deployment hence we performed alpha testing. The alpha testing was conducted on COVID-19 self-testing and the integration of general knowledge base of the information related to COVID-19 pandemic and its daily updates in Rwanda was added and tested using the android application for the usability and the consistence in the information provided by Rwanda Biomedical Center (RBC).

3.2.Modeling malaria surveillance system project timeline.

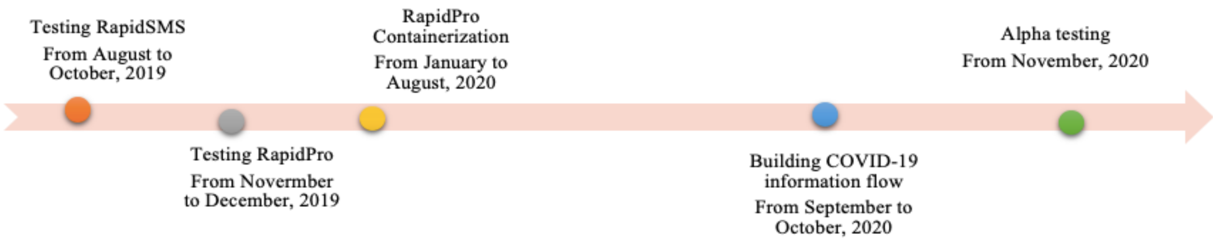


Figure 6: Project timeline

3.3.Design Science Research

Design Science Research also known as constructive research is of importance in a discipline oriented for the creation of successful system artifacts. Several information system researchers have pioneered design science research in information systems, yet over the last 15 years little design science research has been done within the discipline. The lack of a methodology to serve as a commonly accepted framework for design science research and a common template for its presentation may have contributed to its slow adoption (Ken Peffers, 2014).

This chapter describes design science research method which is a framework and guide to conduct our research thesis. The thesis summary is presented before we give an introduction to design science research. The main part of this chapter will describe the use of design science research and the steps taken in our research thesis to fulfill the requirements needed for the incorporating the design science research in our research thesis. Design Science commenced in 1969 by Herbert Simon in his published article the science of the artificial and is seen as a systematic type of designing and concern with knowledge acquisition that relate to design science research and its activity.

The design science as a paradigm has its root in engineering and science of the artifact, it is fundamentally based on solving problem through creative innovations which define the ideas, practices, technical capabilities, and products in which analysis, design, implementation, and information system use which can be effectively and efficiently reached (Bisandu, 2019). In addition to the understanding of organizational use and change, the processes that are behind the development of a communication system need to be understandable in addressing the current issue in information system and data centric approaches.

3.4.Design science research stages

We use the design science research in the designing an information system model that will be used to tackle the resurgence of malaria cases in Rwanda. Based on the designed mode, the real time data will be collected by the community health workers around the country. A well-designed information system using design science research method consists of different stages such as problem identification and motivation, objectives of the solution, design and development, implementation, evaluation and conclusion.

The design science research stages have also developed different principles in which each stage consist of at least with a single principle that will be used to evaluate the feasibility of a given stage and its outcomes.

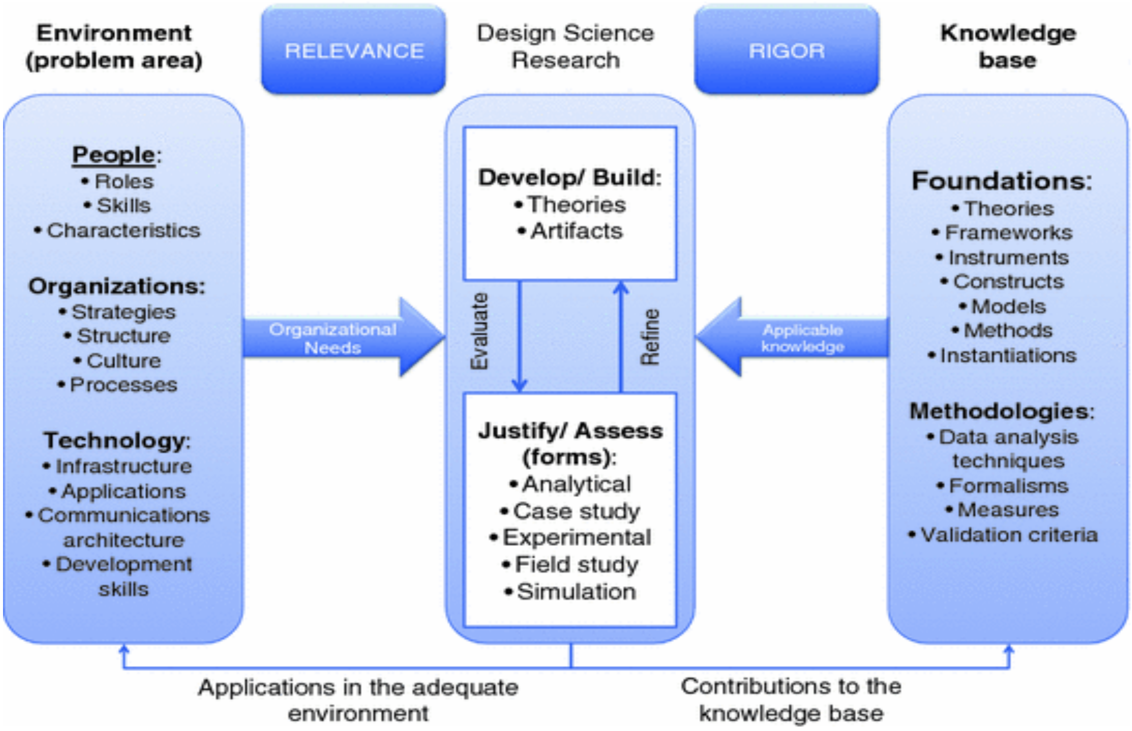


Figure 7: Stages of design science research (DSR). *Source: Hevner et al. (2004)*

3.5.Problem Identification and motivation

Problem identification and motivation is the stage where a researcher should identify, articulate and scope the problem that a given research is going to tackle. This research thesis is driven by the need for an efficient and flexible malaria surveillance system which will enhance the existing malaria surveillance systems and the decisions based on real time data. The system will also facilitate the communication and collaboration of the users starting from the Ministry of health to the health facilities in Rwanda.

This need makes the foundation of principle one in design science research which inspired research in identifying, articulating and scope the problem area that need to be understandable from the current existing malaria surveillance system in the reduction of malaria prevalence using RapidSMS as the first tool applied on malaria surveillance and control in Rwanda.

3.6.Objectives of the solution

Based on the findings on the problem identification and motivation stage, we explored the possibility of improving the existing malaria surveillance system by designing a new model that will improve the functionalities of the existing surveillance system developed using RapidSMS. RapidPro will be used to improve the existing model in designing new malaria surveillance and control flows model based on the information provided by the patient at community level in the country.

3.7.Design and development

The design and the development of the newly malaria surveillance system will be based on the new model developed with reference to the existing one in addressing the problem and data sharing within the decision makers. The model developed has the specific tools that will be used to monitoring the incoming and the outgoing information from the community health workers to the central level and vis versa. The built intervention will be evaluated in all the area that was improved based on the information from the existing system developed using RapidSMS.

3.8.Implementation

The implementation of the new developed model was performed using the RapidPro application extended using the cloud application development framework. The components of RapidPro were containerized and the data management component was added to be able to perform data visualization at the central level. This is the stage where the application was deployed using Docker compose, Docker swarm and Kubernetes to be able address all the challenges that can be presented in its deployment.

3.9.Evaluation

The evaluation was performed in designing COVID -19 chatbot that will used in collecting the information from the community using the android application integrated in RapidPro. The chatbot was designed to test the knowledge base that will be deployed on USSD for tracking COVID-19 case around the country. The test was performed successfully and was adjusted to elaborate where needed and adjusted to fit within the context of COVID-19.

3.10. Communication

The current finding and improvement in the designing of malaria surveillance system is underway towards a journal publication. The obtained data from the testing of COVID-19 information flows was also successfully acquired to adjust the information that will be used on a chatbot to track COVID-19 cases.

CHAPTER FOUR: RAPIDPRO SYSTEM DESIGN AND IMPLEMENTATION

4.1.RapidPro Application

RapidPro is an open-source software that was built to scale the operation of mobile application in health data collection especially in the disease's surveillance and control. It is user friendly than its counterpart RapidSMS with the integration of more communication channels extended from the simple text message (SMS) to both the application to person (A2P) and the person to application communication (P2A). The usage of person to application also known as a chatbots have gain an attention with the introduction of machine learning (ML) and artificial intelligence in the automation of routine processes and tasks execution to mitigate the daily community health issues using mobile based applications.

4.2.RapidPro Application components

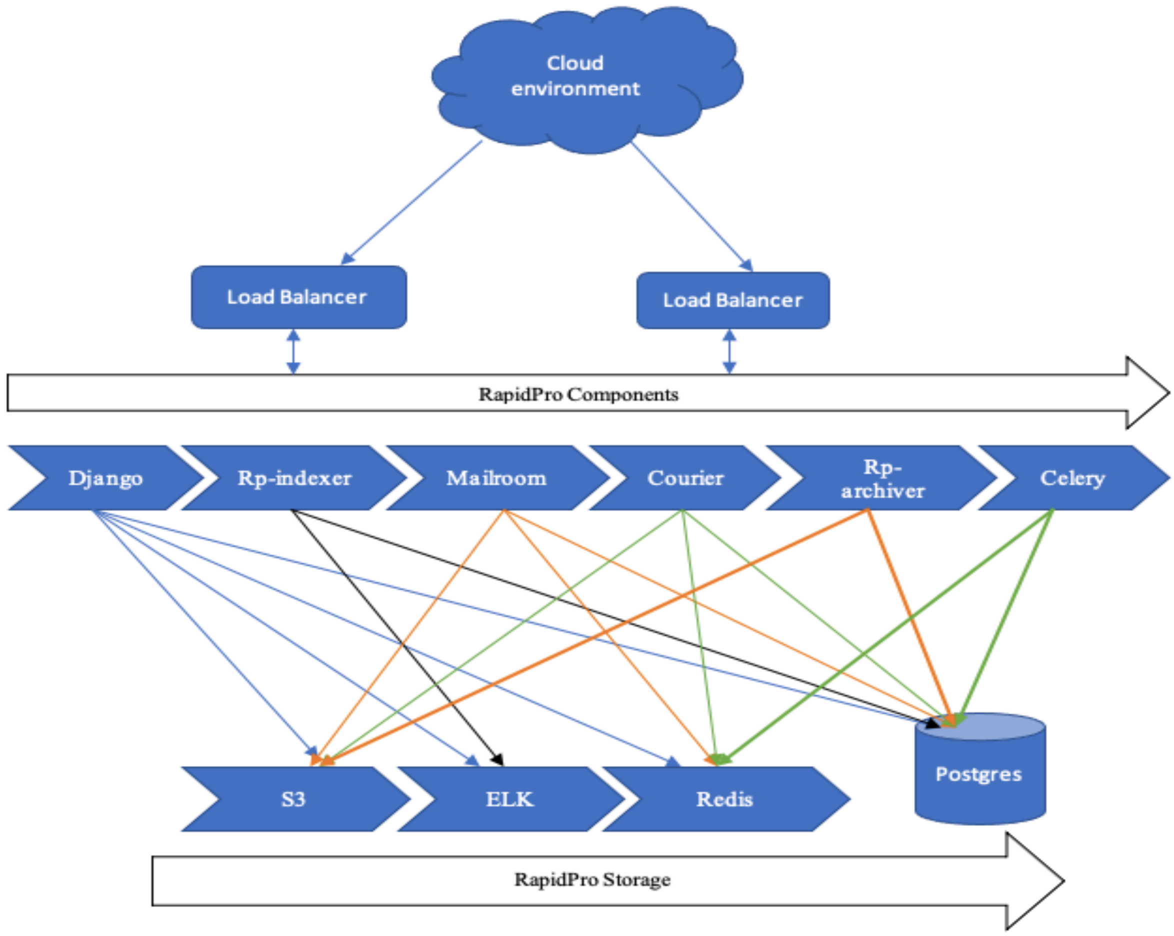


Figure 8: RapidPro architecture and services.

4.2.1. Django

It is a python framework that simplify the development of the web application. It is the basic of RapidPro application user interface which connects the frontend components through its Django views. The Django views also used to manage the logic in the creation of flows, managing the contacts and managing the user creating in the administrator interface.

4.2.2. Celery

The celery executes the background tasks that take long time in execution within RapidPro application. The management of the background tasks are executed through the celery queue. The long-time running tasks such as the export of the flows, contacts and the different cron tasks are scheduled to run in the background for the reduction of the data mismatch.

4.2.3. Courier

The courier component in RapidPro application is the service in charge of receiving and sending the messages. The messages are sent through different aggregators that are the owner of the communication channels. It contains the endpoints that are connected to the external aggregators and helps in the execution of the background processes tasked of sending and receiving the messages. The courier also plays a big role in the handling of the channels that are connected to RapidPro in both the person to application and the application to person communication.

4.2.4. Mailroom

The mailroom component in RapidPro application is the service in charge of executing and handling the flows. The flows are the main components that builds the user communication through the cascading of the information in which the user will complete in a given data collection tasks. The submission of the reminders to the data collectors using message broadcasting is also executed in mailroom. The mobile application channel uses also the mailroom in executing and handling the data sent through mobile application.

4.2.5. Rp-indexer

The rp-indexer is the RapidPro application component in charge of importing the RapidPro contacts to the Elasticsearch in easing the contacts searches. The indexing of the contacts helps in the data indexing in Elasticsearch and creating of the dashboards through in Kibana.

4.2.6. Rp-archiver

The rp-archiver is the RapidPro application component is charge of archiving and storing the sent messages. The messages that are older than 90 days are removed from the database and transferred to rp-archiver. The messages that are deleted from the database are stored in rp-archiver in which those messages are used from there to avoid the overloading the database.

4.2.7. Flow

The flow is the main component of RapidPro application in charge modeling the questionnaire that would be filled by the community health workers. It has two components interconnected together to execute the flows. The flow editor is the dependency of RapidPro which is in charge of authoring and editing the flows. The Goflow is the flow component in charge of executing, validating and migration which ease the heavy lifting on mailroom in running the flows.

4.2.8. Android

The android component in RapidPro is composed of android channel which plays a role of listening to the incoming messages sent by the community health workers and deliver them to the RapidPro application and the second component is the android surveyor which is the offline android application that run the flows offline on there is no internet available in the location of the community health workers.

4.3. RapidPro application stack

RapidPro application was developed as a software as service (SaaS) for the extension of the services provided by RapidSMS. The functionality of RapidPro application works as the function as service (FaaS) with the rapid distribution to address the issue specified in use case.

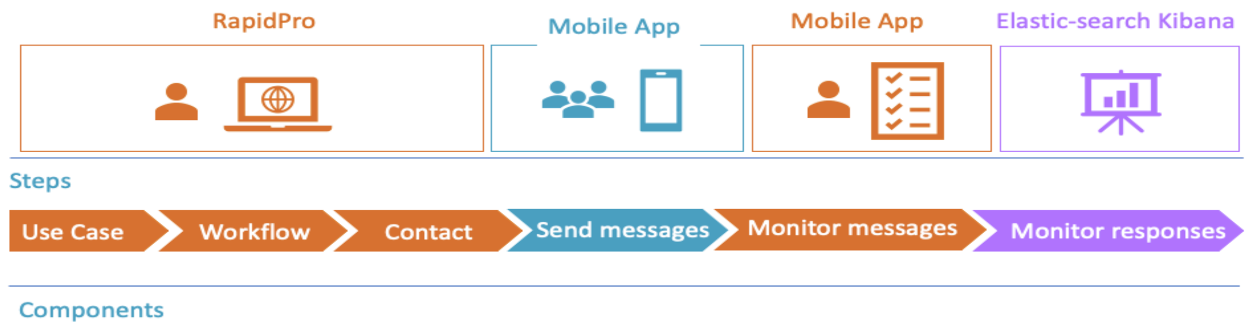


Figure 9: Front-end level components of RapidPro

4.3.1. DevOps steps for application development

4.3.1.1. Continuous development

The integration of agile software development life cycle in the application development have benefited the software development industry in the utilization of small groups for the application development. The small groups adopted the DevOps processes where the development teams are integrated with the operation teams.

The usage of continuous development has shown the advantages compared to the traditional methods with the faster delivery of new application features, delivering a quality code, avoid risk and the usage of less resources compared to the traditional methods. The continuous development has also shown the advantageous in the increasing of the productivity of the agile groups within the application development.

4.3.1.2.Continuous testing

The development of the application using the agile software development life cycle require the automatic testing of the deployed code timely. The testing of the deployed codes helps in ensuring of the quality and the usability of each component from each group hence generate a quality and tested application. The continuous testing has the advantages of increasing the effective collaboration and the quality of the component delivered and pipeline.

4.3.1.3.Continuous integration

The development and testing of the application unit helps in the integration of the newly developed codes. This increases the faster adoption and merging of the developed code in the general repository. The integrated component comes with the application new features and the application scalability both in the horizontal and vertical dimension. The continuous integration has a role of increasing the team productivity, faster bug fixer and faster update delivery.

4.3.1.4.Continuous deployment

The combination of successful processes at the continuous development, continuous testing and continuous integration helps in the automation of the application deployment. The continuous deployment has the role of automating the application integration through the deployment of all the components from the continuous integration.

4.3.1.5.Continuous monitoring

The continuous monitoring is the last phase of the DevOps processes in the monitoring of the application is used to identify the security issues and the bugs in the organization application. The continuous monitoring plays the role of application efficiency and the scalability within the organization.

4.3.1.6.DevOps processes in application development

The DevOps helps the agile team to develop rapidly the product with a considerable time with a small functional component of the application. The continuous development helps in the rapid integration of the of the small component development to the existing components which increases the application delivery on time. The continuous deployment helps in the delivering of the application on time and the rollout of the available component to the end user on time.

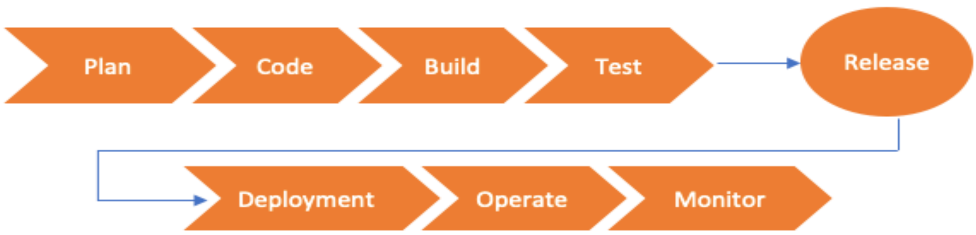


Figure 10: DevOps processes in application development

The DevOps processes requires the integration of the remote repository with the processes. The remote repository plays a role of automating the processes that runs from the local repository or a local computer to the remote servers to host the codes and running the automation jobs.

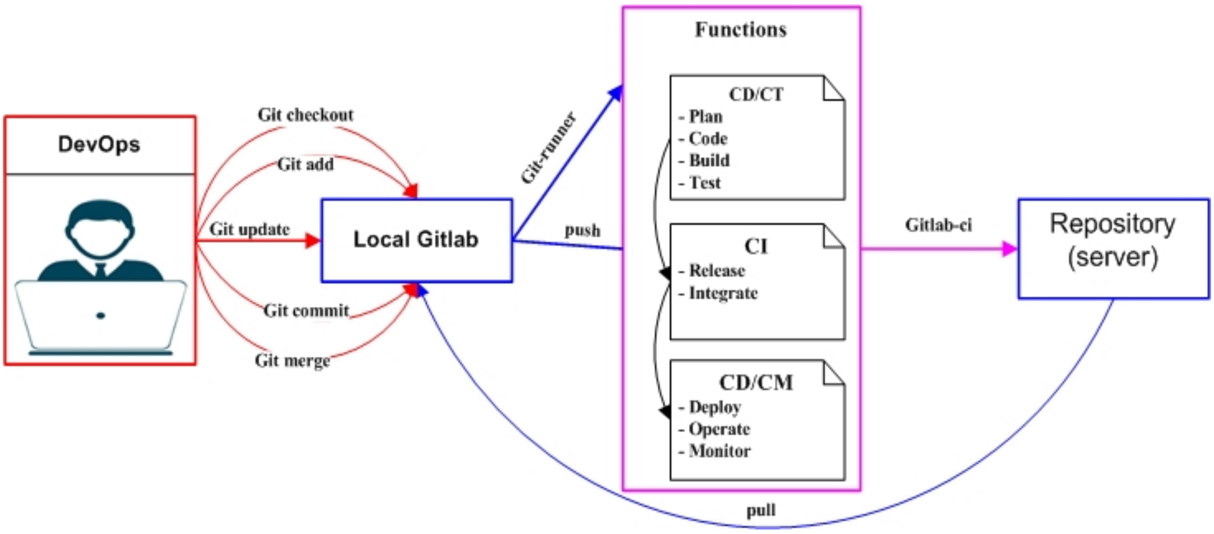


Figure 11: DevOps development stages with Gitlab

4.4.OS level virtualization in RapidPro

4.4.1. Docker

Docker is a platform for developing, running and shipping the applications. The developed applications are packaged into the small component's unit for the efficient shipment from one computer to another. The applications are separated from the infrastructure to be able to develop the application quickly and efficiently.

The Docker platform provide the flexibility in packaging the application through its isolated environment namely container. The containers are the lightweight components of a Docker platform in which the run within a host kernel. The containers do not need the hypervisor load in running the application as the virtual machine because they use the same resources as the host machine in which they are deployed (Lane, 2020).

4.4.2. Docker container

The Docker container is the running instance of a Docker image which hold the complete package that is required to execute the application. The Docker image is built from the Dockerfile which is also a text document that contains a list command to be invoked by a user in assembling the images.

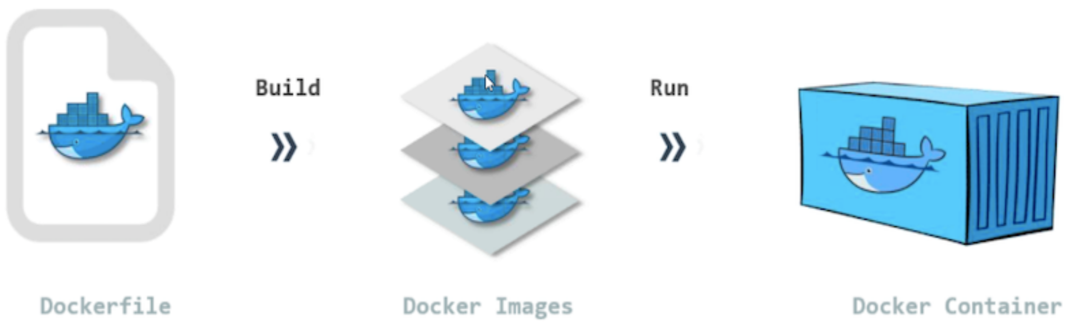


Figure 12:Docker container

4.4.3. Docker engine

A Docker engine is the client server application that links both the client and the server application that are running a dockerized application. The Docker engine is composed of the server, the command line interface and the RESTful API which specify the running processes of the application and its communication to the server.

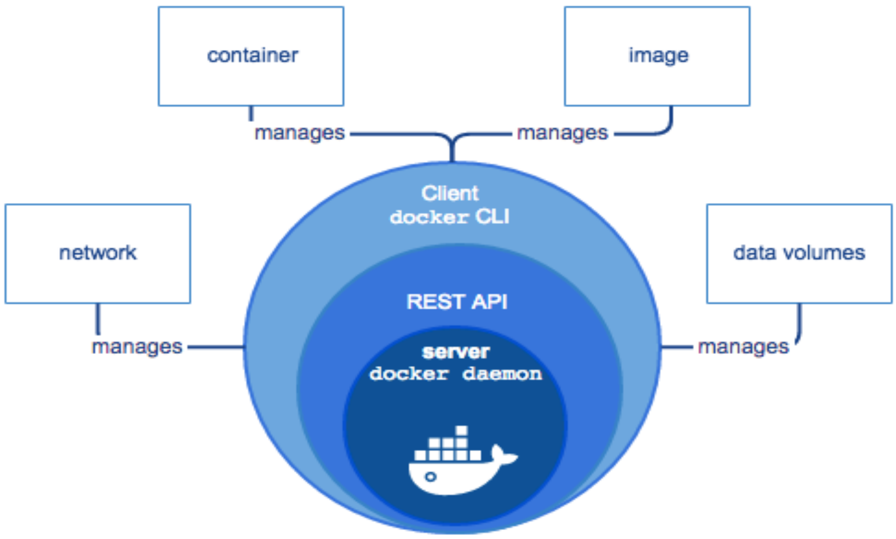


Figure 13: Docker engine

4.4.3.1.Docker architecture for microservice development

The Docker system architecture is based on the communication between the client and the server also known as the daemon. The communication is done through the RESTful API or the remote communication between the client side and the server side that host the application processes. Both the daemon, the client and the registry communicate through the RESTful API and create the respected network between them (Yegulalp, 2019).

The Docker daemon plays the role of listening to the RESTful API requests and the storing of the Docker resources such as the images, containers, volumes and the network whereas the client execute the Docker commands while communicating to the Docker daemon. The Docker registry plays the role of hosting and storing the created images to the public.

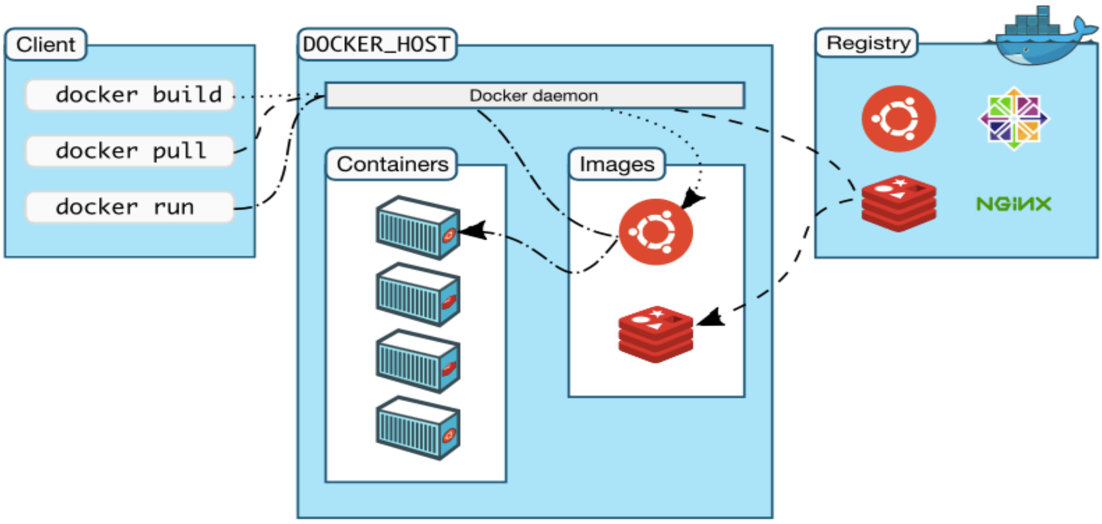


Figure 14: Docker system architecture

4.5.RapidPro application components using microservices

RapidPro application is structured in a microservices for the deployment on both the physical servers and in the cloud. The microservice deployment has a great advantage on both the horizontal and vertical scalability of the RapidPro application including the flexibility in handling system load.

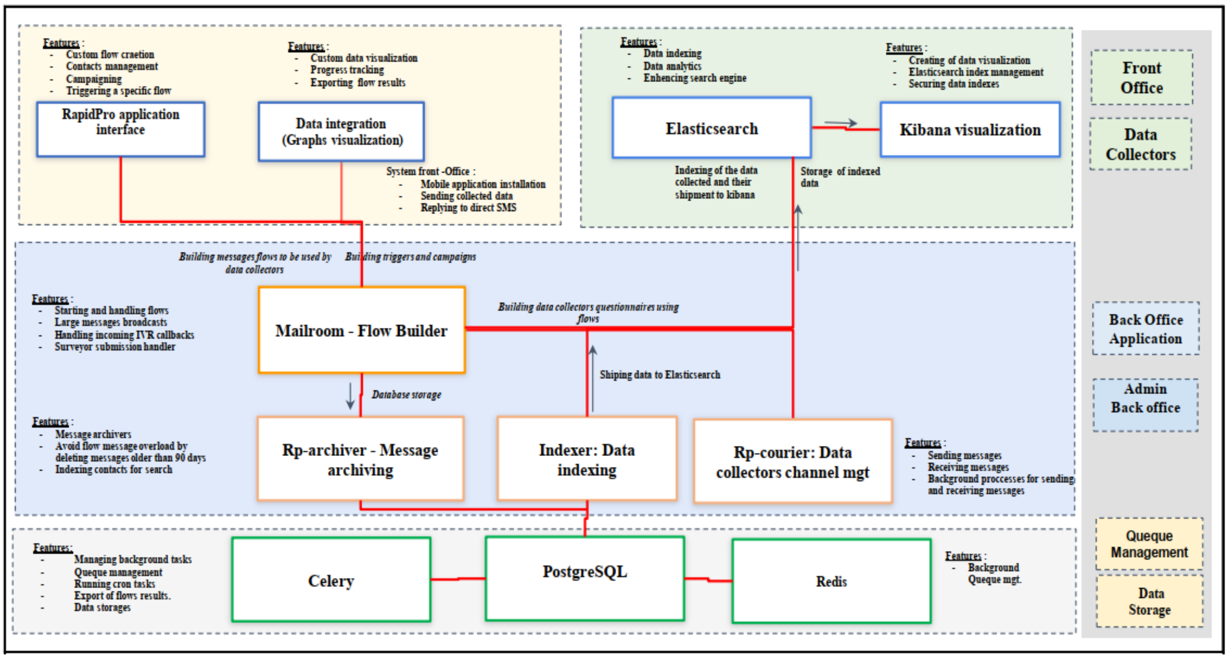


Figure 15: RapidPro microservices interaction

4.6.RapidPro microservices orchestration

The deployment of different containers as a moving part of RapidPro application helps in the orchestrating all the components together for efficient interconnection and usability of the application as whole.

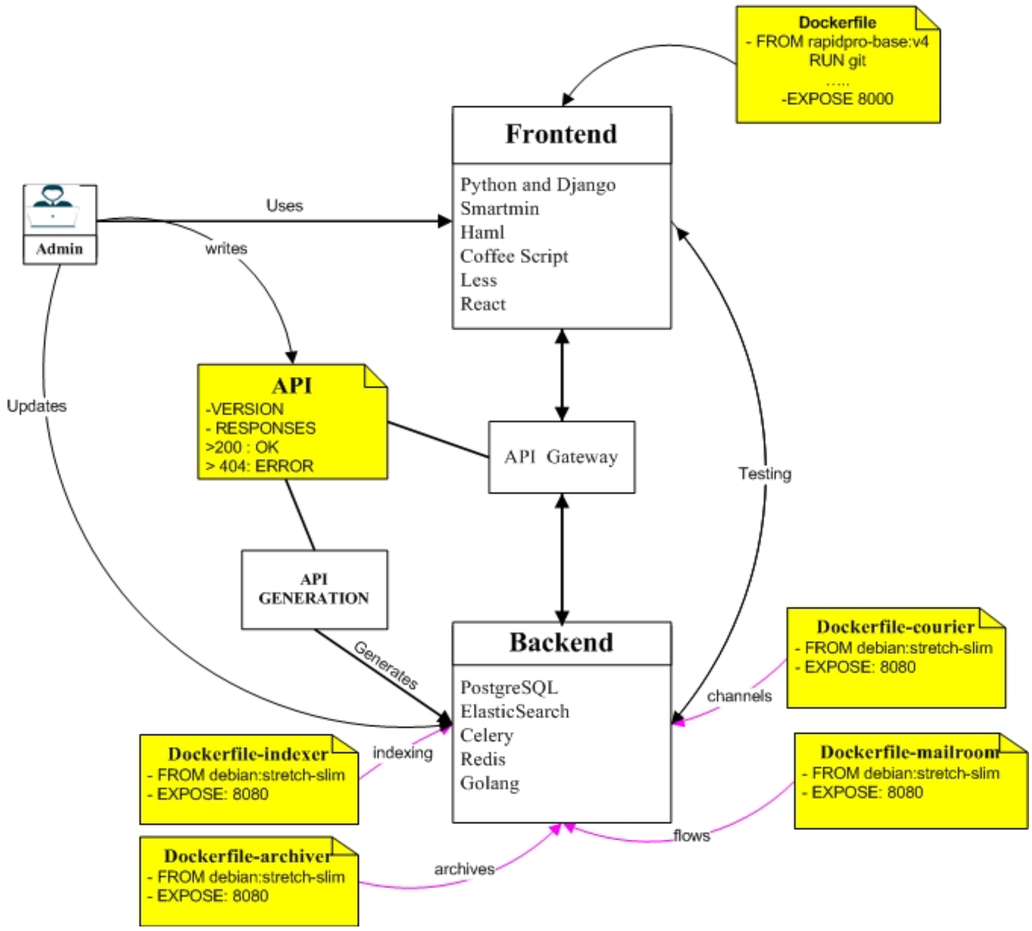


Figure 16: RapidPro services orchestration

4.7.RapidPro microservices deployment

RapidPro application was deployed in Amazon Webservices (AWS) and Google cloud for the optimization of the services and the SMS delivered to the agents or data collectors. The backend of RapidPro application is consisted of four containers such as indexer, archiver, courier and mailroom. The four containers are connected to the storage containers which is PostgreSQL, the Redis that manages the queue and Celery that manages the application workers. The Elasticsearch plays a role of storing the contact indexes that will be used to ship the contacts message to Kibana for the creation of dashboard.

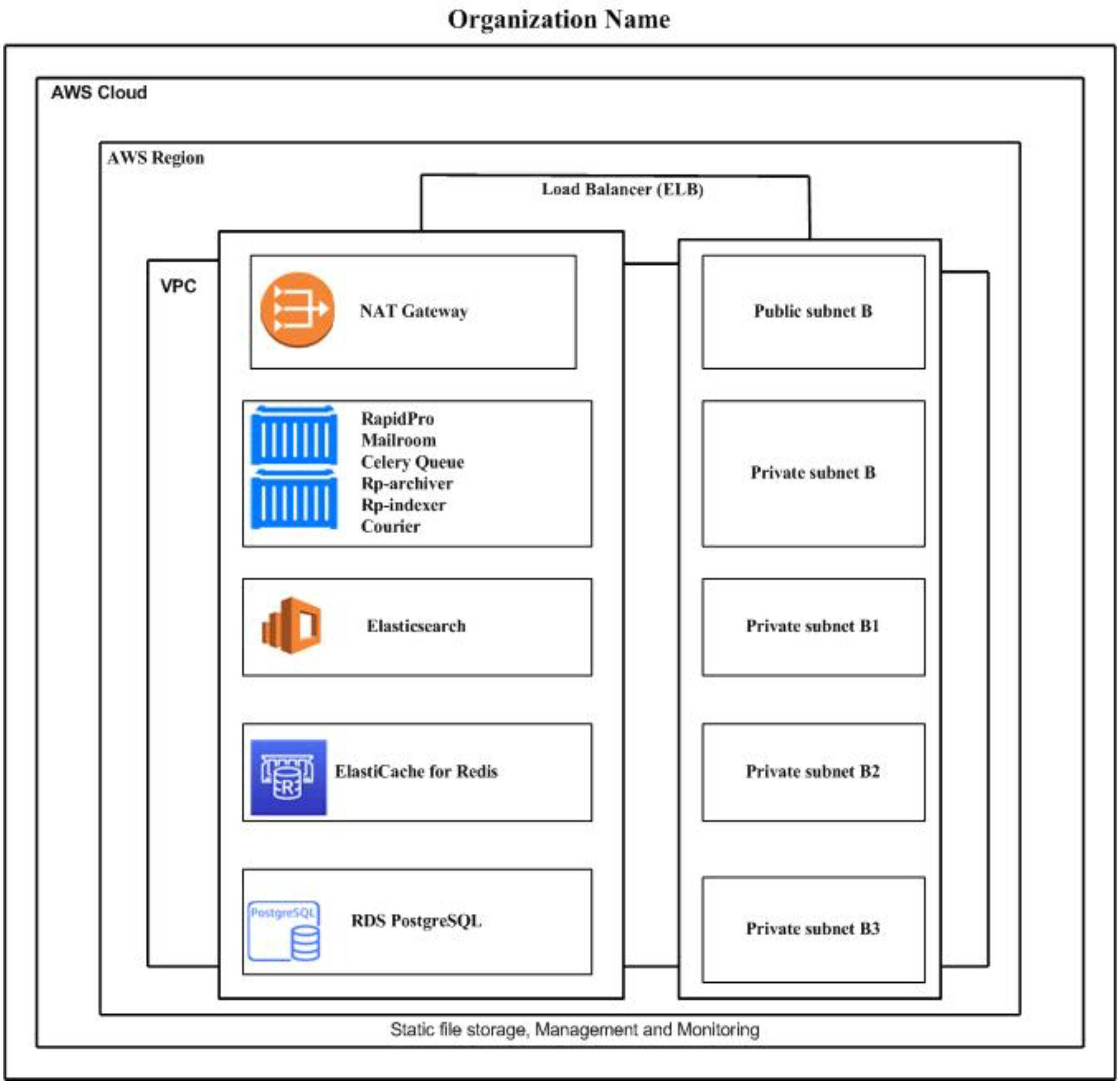


Figure 17: Single zone AWS deployment of RapidPro application

The stability and flexibility of the application deployment depends on the way a given application architecture is designed for a cloud deployment. The single zone deployment of application produces an isolation of an application to the remaining zone which reduces the cost of hosting and ease the management of the resources and the storage of the application.

To deploy an application in a single region has multiple disadvantages because it has a single point of failure once the zone that host the application goes down, the whole application goes down. The application deployment in a single zone increases the latency and the service delay. The configuration of the application in a single zone deployment is also easier once configuring the application that is running in a containerized system in cloud (Becky Weiss, 2019).

4.8.ELK stack data management

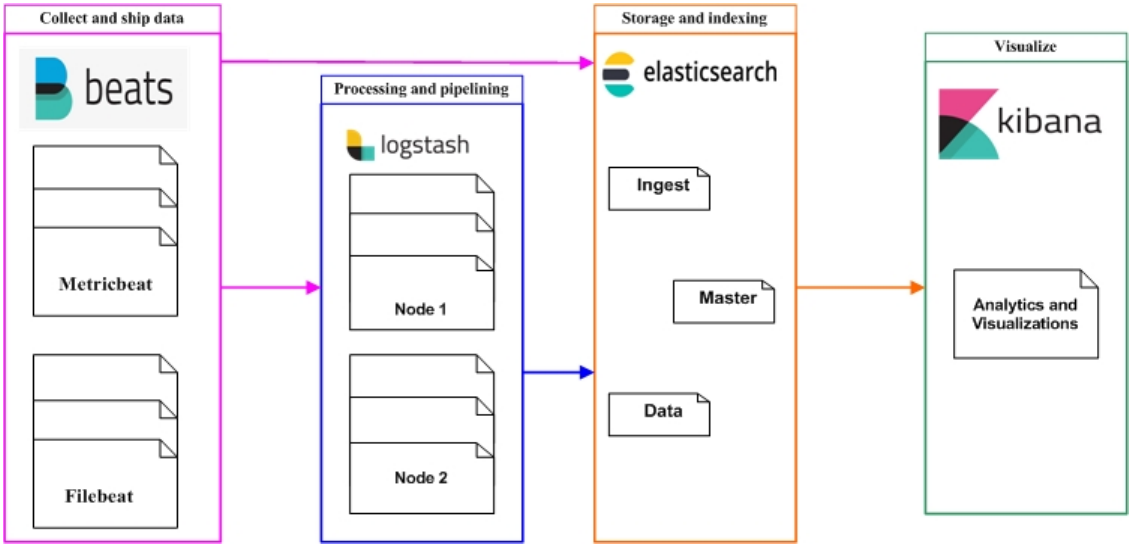


Figure 18: Data management of RapidPro.

The ELK stack stands for Elasticsearch, Logstash and Kibana, it is the stack for logs and data management that uses Elasticsearch as an open source which is in charge of full-text search and data analysis engine. Elasticsearch is based on Apache Lucene which is also has the powerful features on indexing and search as well as spellchecking (Vanderzyden, 2015).

Logstash is the data collection pipeline tool that is used to collects and feeds the data to Elasticsearch to be indexed and sent to Kibana for visualization. The Logstash has three components to be use in the management of the data such as the input for data processing, filters for data filtering and event management and the output for the decision of the event and the logs of the system and the data management (Abueg, 2020).

Kibana is an elk component which is used to create data visualization. The visualization of data enhances the data understanding and the interpretation of the results obtained through the graphs, geospatial maps and the analysis of complex event data. Kibana has different search types used to analyses the Elasticsearch indexes such as the free text searches which is used for searching a specific string, field-level searches which is used to search for a string in a specific field, proximity search which is used for searching the terms with specific character proximity and logic statement which is also used to combine search in logic statement (Abueg, 2020).

4.9.Channel utilization in RapidPro

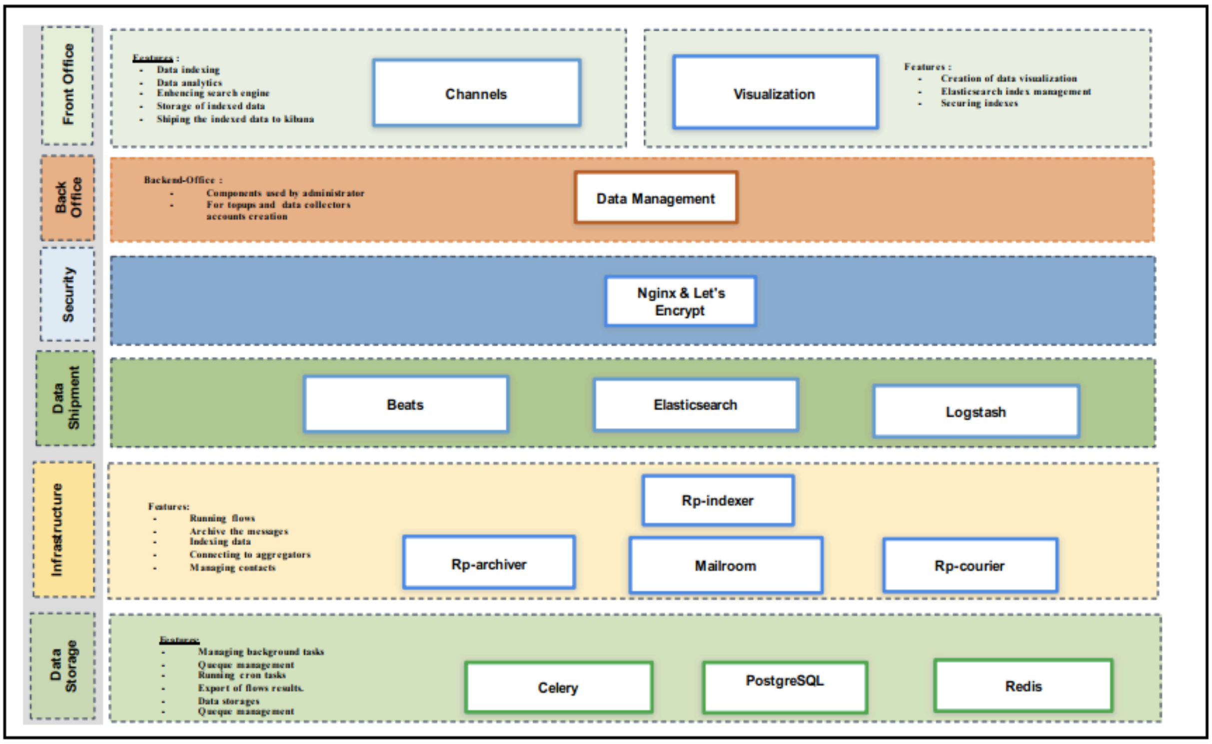


Figure 19: Channel's connection architecture

RapidPro application has multiple communication channels that can be used in the interaction of the end users. The channels are grouped into four groups such as the recommended channels, phone channels, social media channels and the application programming interface (API). The recommended channels such as Twilio and Nexmo are the stable channels that are connected to the third party of the service providers and connected back to the RapidPro application.

The phone channels such as android phone, Clickatell, Infobip, external API, jasmin, kannel, junebag, Mbox and pivo are the dedicated mobile phone applications that are installed in the data collector phone to be able to collect the data required on field. The data collected using those applications are sent in RapidPro application for the storage and the processing through the visualization. The third component of channels is the social media which are responsible for connected data collectors that are using social media application such as Facebook, JoChat, Line, Telegram, Twitter and Viber. The last and not least is the API channel, RapidPro application is able to accept the connection to the external API that can be used to pull and push data from the external dataset.

Figure 20: RapidPro channels

4.10. Android application channel

The android channel is composed of both the channel for offline data collection also known as surveyor and a direct android app that responsible for receiving and sending the messages to the data collectors once the message sent is urgent and need a direct attention. The android application which is responsible for sending and receiving the messages can also be used for scheduling the feedbacks and sending the reminders to the data collectors once one did not send the required data while reporting.

4.11. Security configuration in RapidPro

The security of the application while hosting is essential especially while deploying the containers-based application. The deployment of RapidPro was deployed using nginx as the service to assure the security of the orchestrated services. From the security of the orchestrated services, we also deployed the application behind the reverse proxy to maximize the security of the application and the environment with the application is hosted hence let's encrypt was used as a reverse proxy to secure both the environment and the containerized application.

CHAPTER FIVE: RESULTS AND DISCUSSIONS

RapidPro should be hosted in the environment that has four layers such as the infrastructure, application, security and service. The infrastructure layer is composed of all the resources that are required to run the application as whole including the docker images that will be used to generate the respective containers of RapidPro application. The application layer is composed of the containers running the application component with the capability of data shipping to the Elasticsearch cluster. The third layer is composed of security configuration to protect the running containers which includes nginx and let's encrypt for reverse proxy configuration. The last layer is the exposing RapidPro application for public usage which should be provide the accessibility of the external users to the application through a domain name (Figure 21).

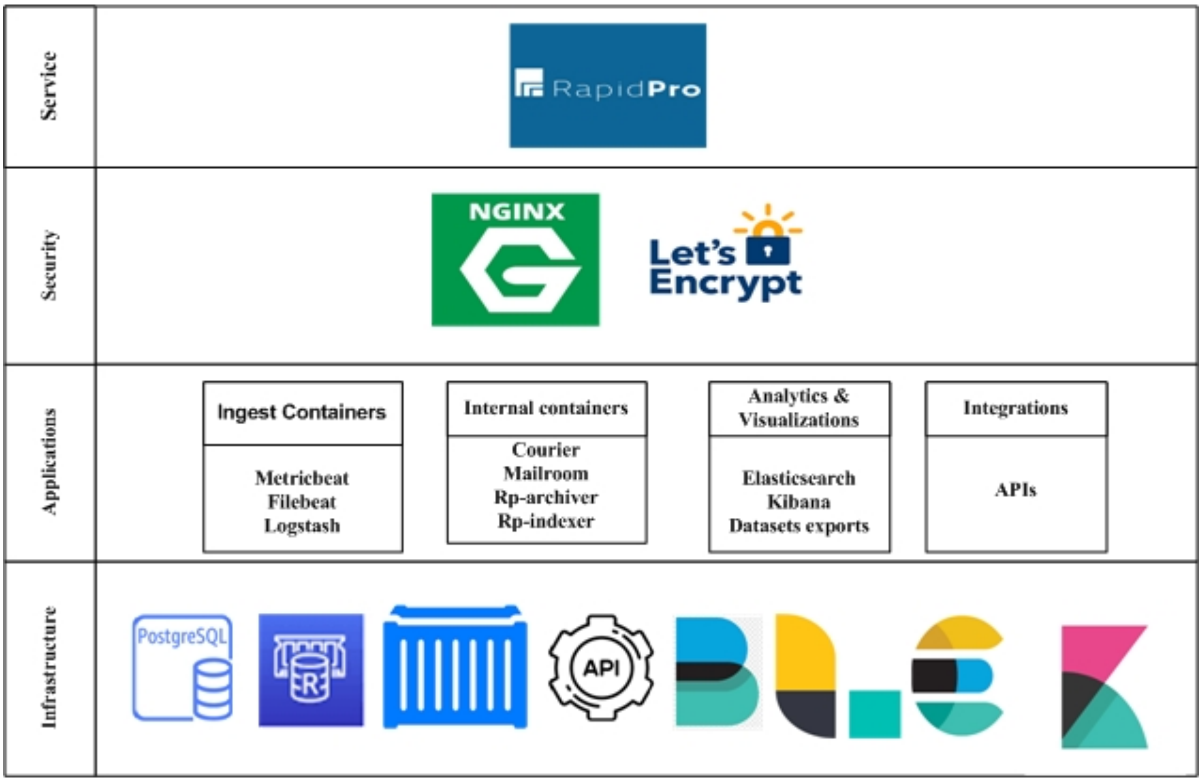


Figure 21: RapidPro security configuration

The configuration and deployment of RapidPro in Amazon Webservices (AWS) follow the above method with a containerized environment using Elastic Compute (EC2). The operation of all the containers is performed behind the proxy for the security purposes. The nginx and let's encrypt are coupled to serve the application security once exposed to the public in the for the vulnerability's mitigation and the enhancement of the security of the containers.

The infrastructure is made of containerized images such as PostgreSQL, Redis, RapidPro and Elasticsearch which generates the respective containers that run the applications for both physical and cloud deployment. The RapidPro application can also be integrated with other applications using the RESTful APIs (Figure 22).

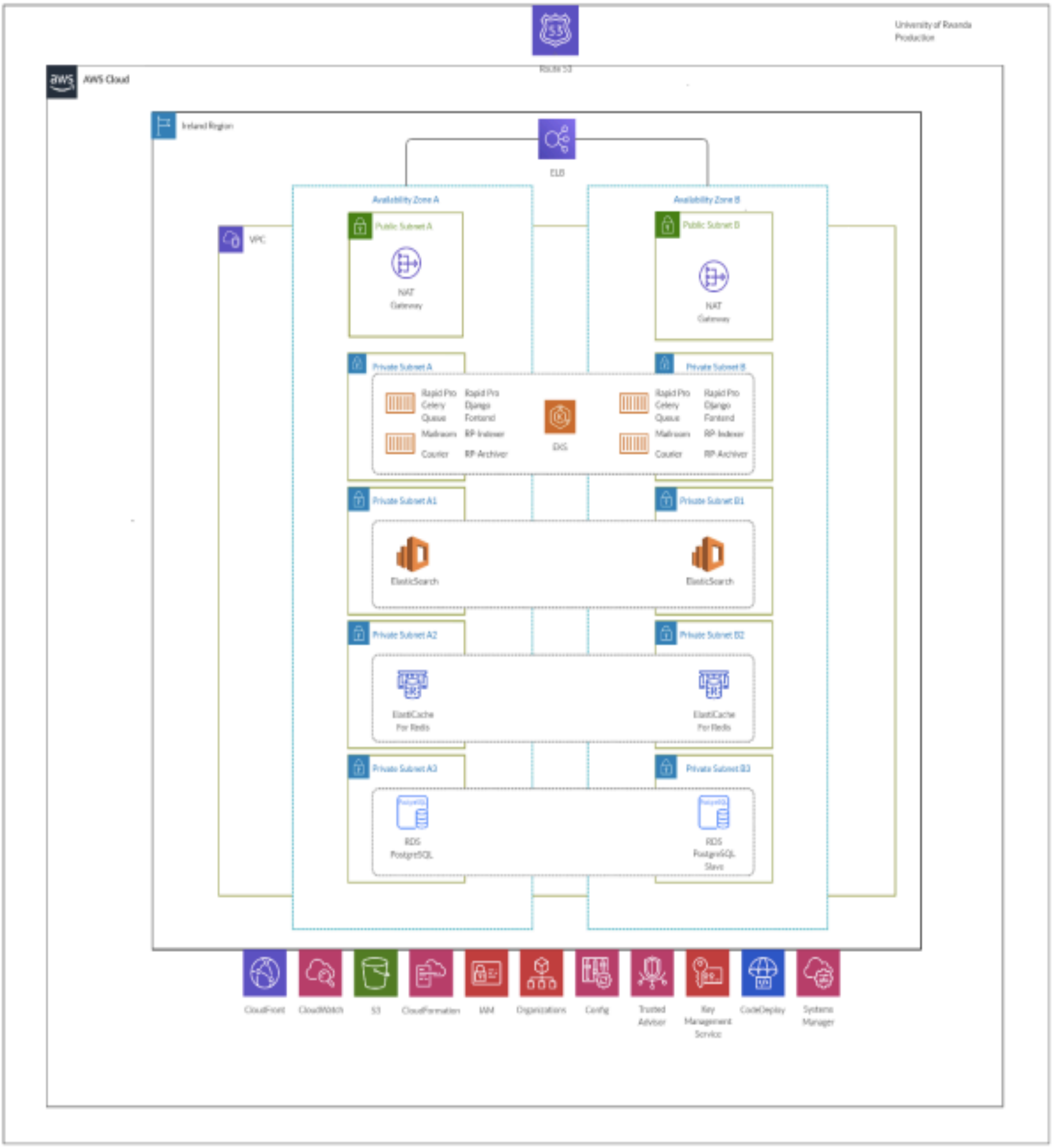


Figure 22: RapidPro application deployment in AWS cloud.

The multi zones deployment of the application avoid the single point of failure while running. RapidPro application was tested only on a single zone deployment and the architecture of the multi zone deployment was also provided in case of production deployment. The multizone architecture will be used for production for an application multi users handling and enhancing its service delivery to the end-user by providing the replicant and the cloud watch for monitoring of the service accessibility and the resources utilization.

5.1.Alpha testing of RapidPro

5.1.1. Malaria cases management information flows in RapidPro

The alpha testing was performed using malaria cases management flow designed using the information given by Rwanda Biomedical Center (RBC). The department of Malaria and other parasites diseases which provides both the Health Management Information System (HMIS) data since 2015 and the RapidSMS notification system data since its deployment in 2018.

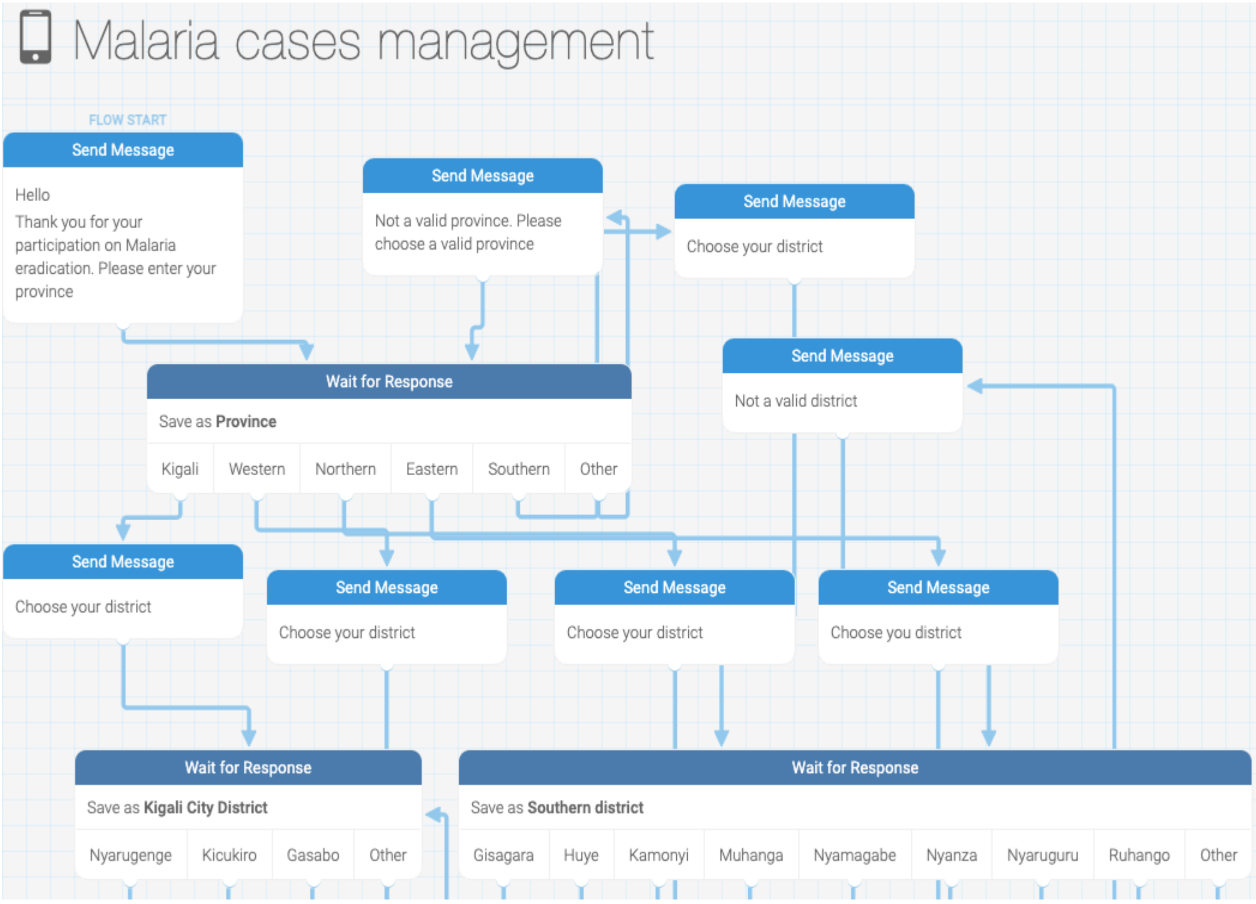


Figure 23: Alpha testing flow for Malaria case management

The flow is built to show how the information is structured and connected from checking the new malaria cases, the rising of cases with respect to the district and the prevalence of malaria in the country. The information is tested using the android application as the first channel integrated to RapidPro application to evaluate the feasibility of individual reporting to the central server for national malaria eradication in Rwanda. The figure 24 demonstrate the cases visualization per district and the number of individuals who have submitted the data to the central server.

5.1.2. Alpha testing with android application

The alpha testing was performed to identify the possible problems that can be arise in the production environment while using RapidPro application. The presented issues were mitigated including the information flow and release of the final version of the application on GitHub repository. The figure 24 shown malaria cases management flow and the respective android application used in testing the feasibility of the designed flow in a containerized RapidPro application.

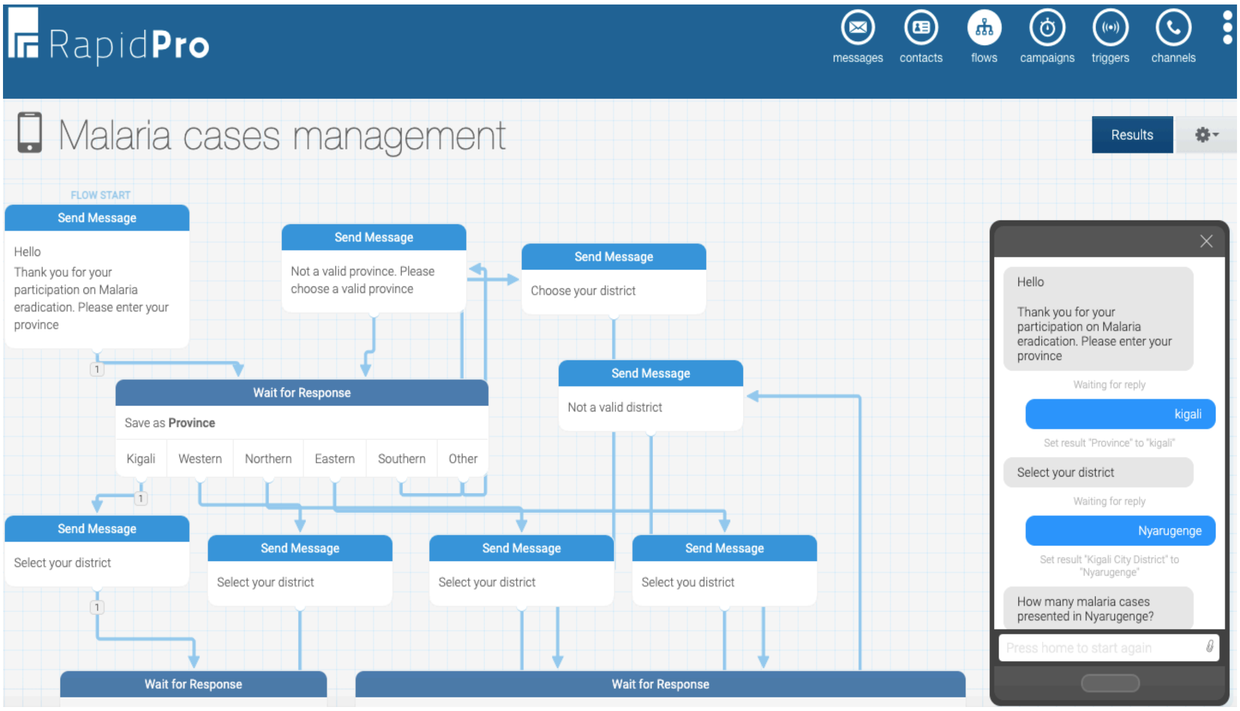
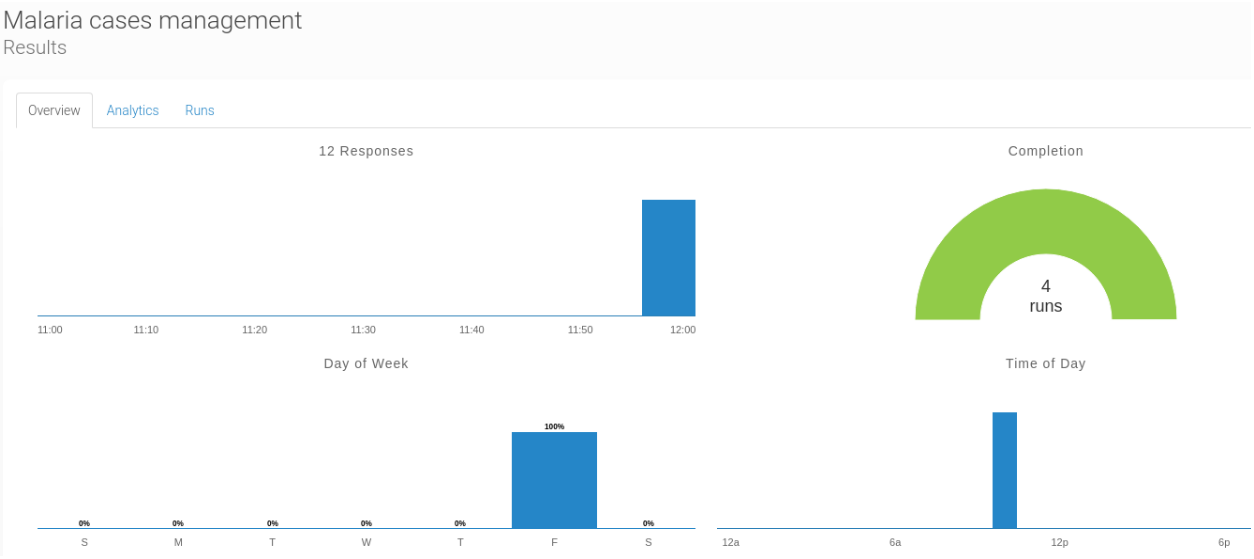


Figure 24: Running flow using Android application in RapidPro

5.1.3. Data analytics for Malaria cases management



The analysis of data was performed using ELK stack which is composed of Elasticsearch, Logstash and Kibana. The severe malaria cases were displayed showing the number of malaria cases against the district. The figure 25 showed that Nyagatare district has a low number of severe malaria cases whereas Nyamasheke has a higher number of severe malaria cases.

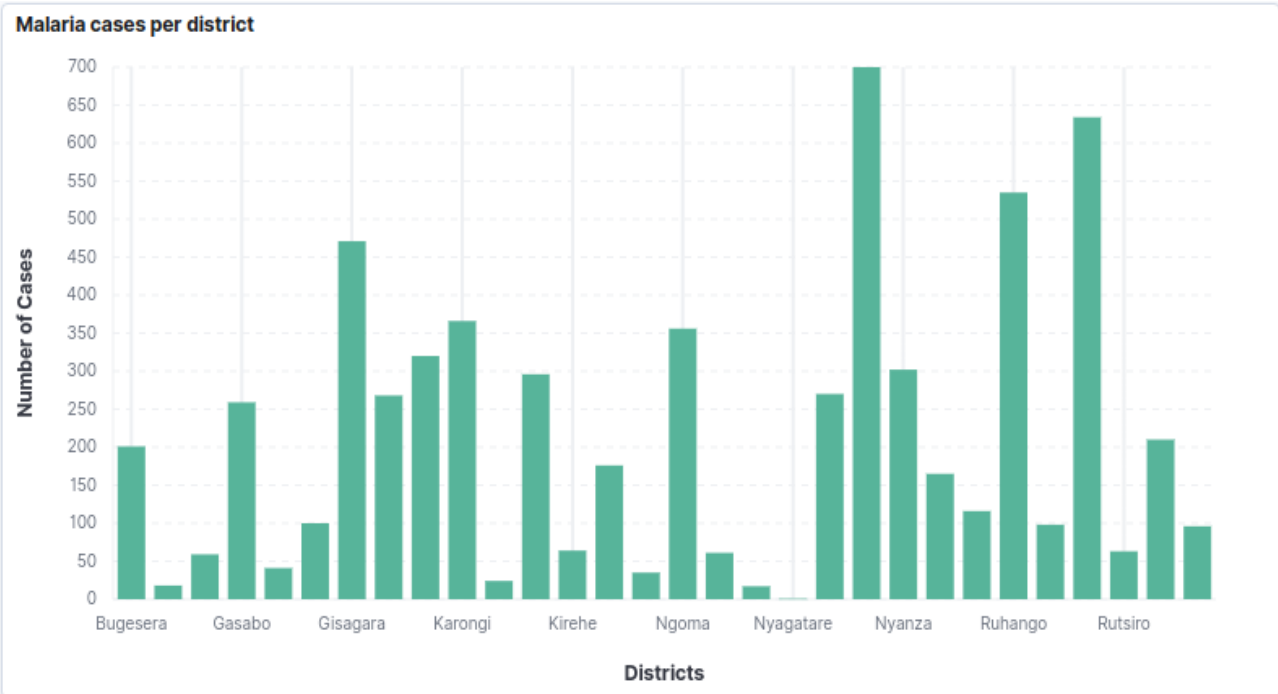


Figure 25: Data analytics of severe Malaria cases

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

This project was based on evaluation and improving of the existing malaria information flow designed in RapidSMS especially on the severe malaria and stock out notification system. The previous was designed to ease the reporting of severe malaria and the drugs stock out. The information flows from the community health worker to the decision maker in which the latter is able to draw the solution based on the information obtained.

The scalability of the system developed in RapidSMS was almost impossible because the system was hardcoded and the additional components should also be hardcoded to extend to other parameters that are required for the enhancement of the decision taken based on the accurate data provided by the community health workers.

The new system under RapidPro will be useful for adding the required parameter because its component can be extended using its major component called flow editor under mailroom. The parameters are added using the new flow that will increase the required parameter to be able to tackle its progress towards malaria surveillance and elimination.

The deployment of the cloud-based applications requires more efforts and resources in which students cannot afford alone. In this regard I recommend for the University of Rwanda, College of Science and Technology to have a testing environment for students especially for those that are running the real-time projects that need to be tested in real life environment.

The combination of development and operation of application deployment need also a hosted environment in which Gitlab and GitHub can be used. For this regard, the College of Science and Technology can help in setting-up the student's project development instance that can be used to for application development and testing.

Lastly, the collaboration of the University of Rwanda and the outside industry is also need for enhancement of the application development and their usage in tackling different problems available in the community.

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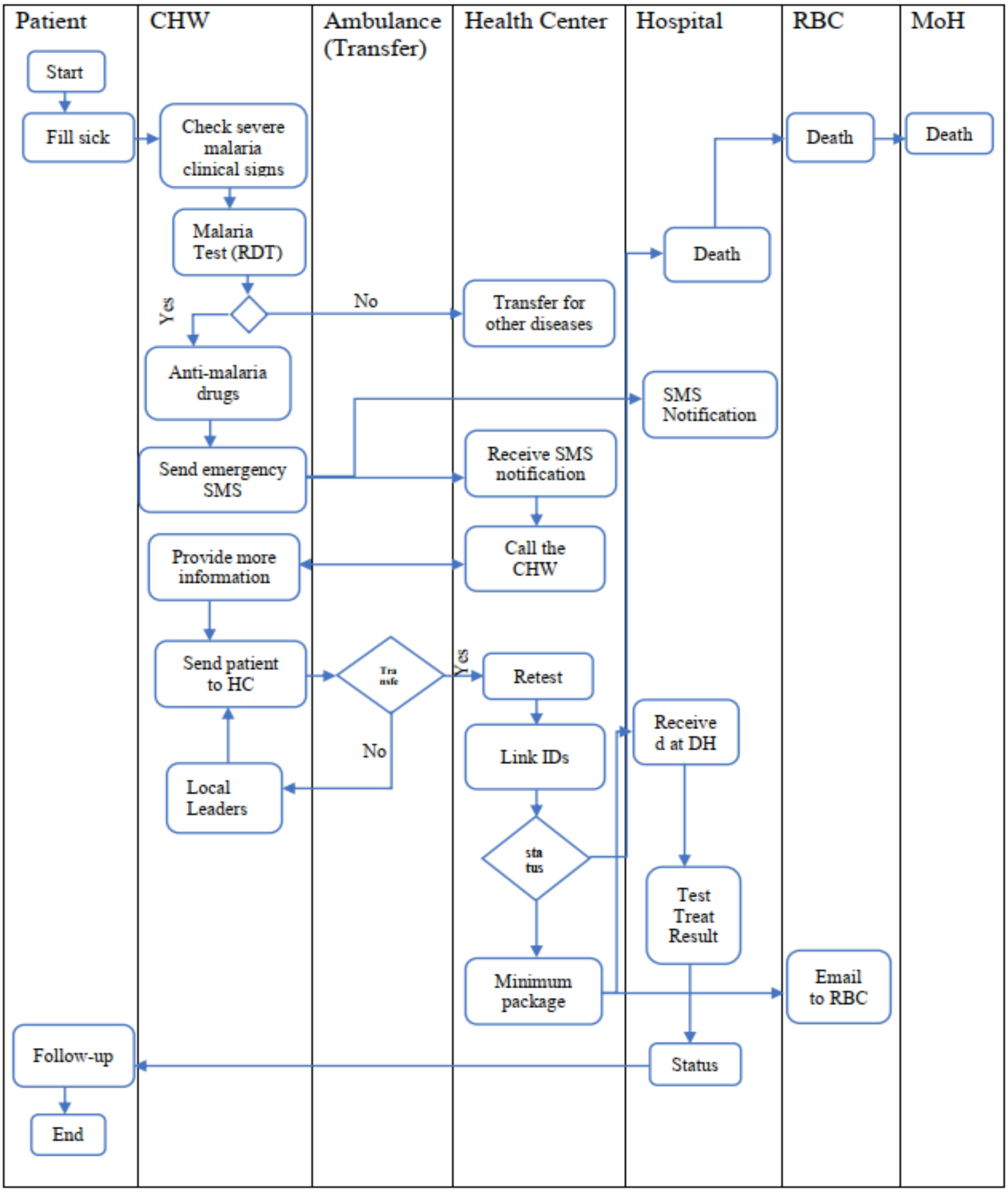
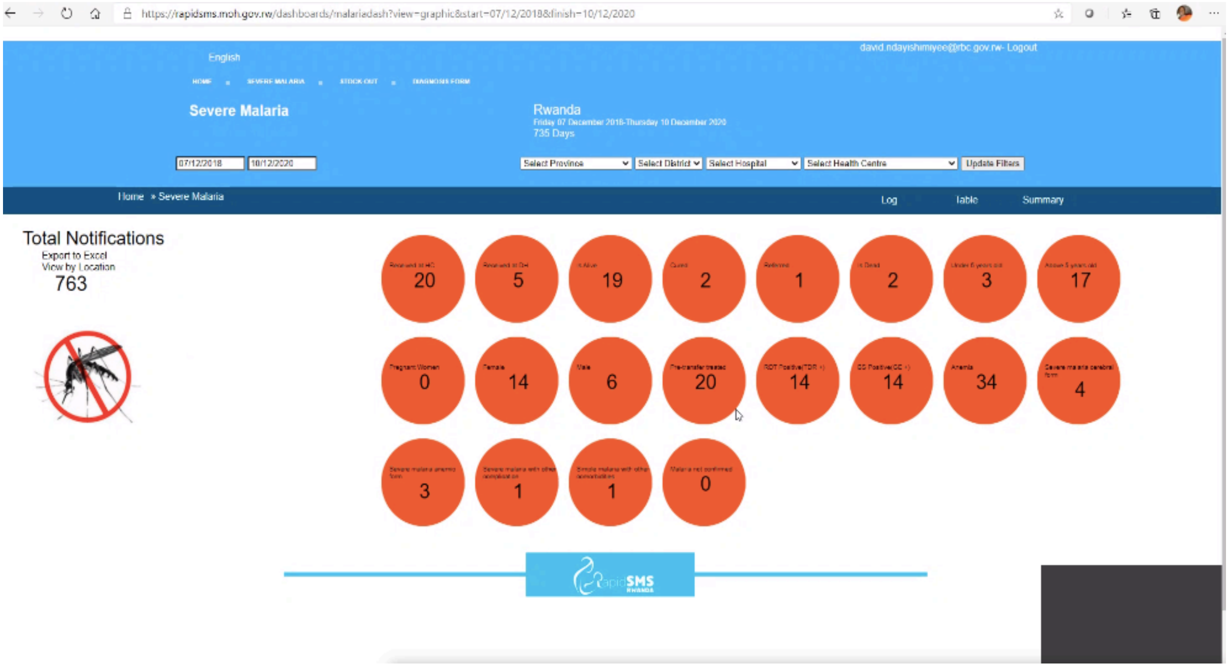
APPENDEX A

RapidSMS system for Malaria case notification.



APPENDEX B

RapidSMS dashboard for Malaria case notification



APPENDEX C

RapidPro dashboard for Malaria cases management