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A Mobile based Tuberculosis contact tracing and screening system

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A Mobile Based Tuberculosis Contact Tracing and Screening System

By

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Declaration

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the dissertation contains no material previously published or written by another person except where due reference is made in the dissertation itself.

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Abstract

The National TB programme in Kenya is facing some significant challenges as relates to TB contact tracing and screening. Tuberculosis contact tracing and screening is typically conducted in resource-limited settings with paper forms. This approach presents a number of challenges, first is the challenge of covering vast geographical locations with the limited number of health workers. The approach is also limited by inefficiencies in data collection, storage, retrieval and poor data quality. These limitations of the current contact tracing and screening, have made the National TB Programme in Kenya fall short of reaching its objectives in combating TB and consequently the country has experienced an increase in TB rates. This scenario creates a significant gap, which the researcher can help close by improving the current way of TB contact tracing and screening.

This study aimed to come up with a mobile-based system for TB contact tracing and screening using USSD technology and Android technology. Agile methodology was adopted as the software methodology for developing the system. An Android application was developed for the use of identifying TB contacts, alerting TB contacts to screen their symptoms and risk factors and recording laboratory results of TB contacts. Further, a USSD application was developed to allow TB contacts to select their symptoms, risk factors and to check status of their screening results. Both the USSD application and Android application were integrated with analytical back-end for presenting summary of the activities of contact tracing and screening. The TB contact tracing and screening system was developed and designed to benefit from the high mobile phone availability and usage in Kenya, to improve TB contact tracing and screening and tackle the inefficiencies of surveillance based on paper records. The system also improves decision making by TB policy officials by providing them with relevant surveillance reports, analytics and statistics.

Keywords: TB contact tracing, TB contact screening, TB mobile applications

Table of Contents

Declaration i

Acknowledgement ii

Abstract iii

List of Figures ix

List of Tables xi

List of Acronyms xii

Definition of Terms xiii

Chapter One: Introduction 1

1.1Background Information 1

1.2 Problem Statement 3

1.3 Research Objectives 4

1.4 Research Questions 4

1.5 Study Justification 4

1.6 Scope of study 5

Chapter Two: Literature Review 6

2.1 Introduction 6

2.2 Tuberculosis Contact Tracing and Screening 6

2.3 Tuberculosis Contact Tracing and Screening in Kenya 7

2.3.1 Documented Case of TB Contact Tracing and Screening in Kenya 8

2.4 TB Contact Tracing and Screening Models and Approaches 8

2.4.1 Contact Tracing Through Use of Electronic Patient Records 8

2.4.2 Contact Tracing and Screening Using Web-Based Strain Typing 9

2.4.3 Contact Tracing and Screening through Social Network Analysis 10

2.4.4 Contact Tracing and Screening Using Geographic Information Systems 10

2.4.5 Contact Tracing and Screening Using Mobile Solutions 11
2.4.6 Contact Tracing and Screening Using Genomics 11
2.5 Challenges Faced By TB Contact Tracing and Screening Models 12
2.6 Documented Contact Tracing and Screening Systems 13
2.6.1 USSD TB Contact Tracing and Screening System in Botswana 13
2.6.2 Electronic Tb Contact Tracing and Screening on a Large Scale in China 14
2.6.3 A Comprehensive Web-Based Tool for Programmatic Management of TB 16
2.7 Review of Software Development Technologies 17
2.7.1 USSD Technology 17
2.7.2 USSD Architecture 17
2.7.3 USSD vs. SMS 18
2.8 Conceptual Framework 19
2.9 Summary 20
Chapter 3: Research Methodology 21
3.1 Introduction 21
3.2 Software Development Methodology 21
3.2.1 Planning Phase 22
3.2.2 Requirements Analysis Phase 22
3.2.3 Design Phase 23
3.2.4 Building Phase 24
3.2.5 Prototype Evaluation and Testing Phase 25
3.3 Ethical Issues 25
Chapter 4: System Design and Architecture 26
4.1 Introduction 26
4.2 Results from Questionnaire 26

4.2.1 Age Group of Respondents 26
4.2.2 Number of Contact Tracing and Screening Activities Undertaken 27
4.2.3 Contact Tracing and Screening Systems in Use. 27
4.2.4 Need for a Contact Tracing and Screening System 28
4.2.5 Limitations of the Current Contact Tracing and Screening System 29
4.3 Results from Data Collection and Analysis 29
4.3.1 Functional Requirements 30
4.3.2 Non Functional Requirements 30
4.4 Design Phase 31
4.4.1 System Architecture 31
4.4.2 Sequence Diagram 32
4.4.3 Use Case Diagram 32
4.5 System Design 38
4.5.1 Design Class Diagram 38
4.5.2 Entity Relationship Diagram 39
4.5.3 Database Schema 40
4.6 Security Design 44
4.7 Application Wireframes 45
Chapter 5: Prototype Building and Testing 47
5.1 Introduction 47
5.2 Implementation Environment 47
5.3 System Implementation 47
5.3.1 Proposed USSD Application 47
5.3.2 Proposed Android Application 50
5.3.3 The Web-Application 52

5.4 System Testing 52
5.4.1 Functional Testing 53
5.4.2 Usability Testing 56
5.4.3 Compatibility Testing 59
5.5 System Evaluation and Validation 60
5.6 Summary 61
Chapter 6: Discussion 62
6.1 Introduction 62
6.2 Review of Research Objectives in Relation to the Mobile Application 62
6.2.1 Factors relating to TB Contact Tracing and Screening 62
6.2.2 Existing TB Contact Tracing and Screening Models 63
6.2.3 TB Contact Tracing and Screening System 63
6.2.4 Validation of the Developed Solution 63
6.3 Advantages of the Application as Compared to the Current System 64
6.4 Limitation of the system 64
Chapter 7: Conclusions and Recommendations 65
7.1 Conclusions 65
7.2 Recommendations 66
7.3 Future works 66
References 67
Appendices 71
Appendix A: System Requirements Document: 71
Appendix B: Respondents Questionnaire 75
Appendix C: Usability Testing and Validation Questionnaire 80
Appendix D: Wireframes 81

Appendix E: Screenshots 90

Appendix F: Turnitin Report..... 95

List of Figures

Figure 2. 1 Botswana's USSD TB Contact Tracing and Screening Architecture 14
Figure 2. 2 China's Tuberculosis Information Management System Architecture 15
Figure 2. 3 e-TB Manager 16
Figure 2. 4 USSD Architecture 18
Figure 2. 5 Conceptual Framework 19
Figure 4. 1 Age Group of Respondents 26
Figure 4. 2 Number of Contact Tracing and Screening Activities 27
Figure 4. 3 Contact Tracing And Screening Systems 28
Figure 4. 4 Need for Contact Tracing and Screening System 28
Figure 4. 5 Limitations of the Current System 29
Figure 4. 6 Proposed System Architecture 31
Figure 4. 7 Sequence Diagram 32
Figure 4. 8 Use Case Diagram 33
Figure 4. 9 Design Class Diagram 38
Figure 4. 10 Entity Relationship Diagram 39
Figure 4. 11 USSD Main Menu 45
Figure 4. 12 Android Application Main Menu Wireframe 46
Figure 4. 13 Web Application Dashboard Wireframe. 46
Figure 5. 1 Screenshots of Main Menus of the USSD Application 48
Figure 5. 2 Sample Screenshots of Symptoms Selection 49
Figure 5. 3 Sample Screenshots of Risk Factors Selection 49
Figure 5. 4 Screenshots of Checking Status Notification 50
Figure 5. 5 Screenshot of TB Patient Indexing 51
Figure 5. 6 Screenshot of Web Application Dashboard 52
Figure 5. 7 User Friendliness Testing 57
Figure 5. 8 System Functionality Acceptance Testing 58
Figure 5. 9 Acceptability Testing 58
Figure 5. 10 User Interface Aesthetics 59
Figure 5. 11 Validation of System 61

Figure D. 1 Welcome Page 81
Figure D. 2 Login Page 81
Figure D. 3 Main Menu Wireframes 82
Figure D. 4 Symptoms Screening Wireframes 83
Figure D. 5 Risk Factors Wire Frame 84
Figure D. 6 Registration Wireframes 85
Figure D. 7 Notification Status Wireframe 85
Figure D. 8 Login Wireframe 86
Figure D. 9 Main Menu Wireframe 86
Figure D. 10 Case Indexing and Adding TB Contact Wireframe 87
Figure D. 11 Labtest Recording Wireframe 87
Figure D. 12 Web Application Login Wireframe 88
Figure D. 13 Web Dashboard Wireframe 88
Figure D. 14 Symptoms Report Wireframe 89
Figure E. 1 USSD Login Menu Screenshot 90
Figure E. 2 USSD Login Details Screenshot 90
Figure E. 3 USSD Registration Details Screenshot 91
Figure E. 4 Android Login Screenshot 92
Figure E. 5 Android Main Menu Screenshot 92
Figure E. 6 Sign-Up Sheet Screenshot 93
Figure E. 7 Verification Screenshot 93
Figure E. 8 Administrator Login in the web application 94
Figure E. 9 Symptoms Report Screenshot 94

List of Tables

Table 4. 1 Add a TB Contact Use Case 34
Table 4. 2 Dial USSD Code Use Case 34
Table 4. 3 Select Symptoms Use Case 35
Table 4. 4 Select Risk Factors Use Case 35
Table 4. 5 Receive SMS Use Case 36
Table 4. 6 Record Laboratory Test Results Use Case 36
Table 4. 7 View Analytics Use Case 37
Table 4. 8 Database Tables Overview 40
Table 4. 9 Clinicians Table 41
Table 4. 10 Patients Index Case Table 41
Table 4. 11 Contacts Table 42
Table 4. 12 Symptoms Table 43
Table 4. 13 Risk Factors Table 43
Table 4. 14 LabTest Table 44
Table 5. 1 USSD Login Test Case 53
Table 5. 2 Select Symptoms Test Case 53
Table 5. 3 Select Risk Factors Test Case 54
Table 5. 4 Receive Correct SMS 55
Table 5. 5 Add a TB contact 55
Table 5. 6 Record TB Lab Test Results 56
Table 5. 7 Test Done on Android Platforms 60

List of Acronyms

Acronym		Description
CHV	-	Community Health Volunteers
DBMS	-	Database Management System
DOTS	-	Directly Observed Treatment, Short-course
ERD	-	Entity Relationship Diagram
GSM	-	Global System for Mobile
HLR	-	Home Location Register
IPT	-	Isoniazid preventive therapy
LTBI	-	Latent TB Infection
MoH Kenya	-	Ministry of Health Kenya
MOPTAM	-	Mobile Phone Technology Adoption Model
SMPP	-	Simple Messaging Peer-Peer
TBCT	-	TB Contact tracing system
TRA	-	Theory of Reasoned Action
TST	-	Tuberculin skin tests
TB	-	Tuberculosis
UML	-	Unified Modelling Language
UTAUT	-	Unified Theory of Acceptance and Use of Technology Model
USSD	-	Unstructured Supplementary Service Data
VLR	-	Visitor Location Register
WHO	-	World Health Organization

Definition of Terms

Tuberculosis: Tuberculosis (TB) is a disease caused by Mycobacterium Tuberculosis (MTB), which is transmitted through the air or by ingesting infected milk or meat (Bovine TB) and it is both preventable and curable (Caminero, 2008). It affects the lungs (pulmonary TB) but can also affect other organs for instance the extra pulmonary.

TB Contacts: Tuberculosis (TB) contacts are people who have close contact with patients with infectious TB. As they are at high risk for infection (and in line with the End TB strategy), TB contacts should be investigated systematically and actively for TB infection and disease (WHO, 2016).

TB Contact Tracing: TB contact tracing is process that involves following up TB patients to identify and screen contacts who are at risk of contracting TB (Kovarik, 2010). The process begins immediately after identifying a TB case index also known as source patient. The TB case index is identified through use of smear positive results (Kabongo & Mash, 2010).

TB Contact Screening: TB contact screening is a process that attempts to find, test, treat and notify person who might be having a Latent TB infection or disease, which might have been caused because by being in contact with a person with TB disease (Zellweger, 2010). Health institutions are required to screen contacts very fast and within the earliest time after they diagnose someone with TB infection.

TB Patient Index Case: A person with suspected or confirmed TB disease; sometimes this person is referred to as an index case or index patient (CDC, 2014).

Chapter One: Introduction

1.1Background Information

Tuberculosis (TB) is one of the infectious diseases that continue to be a public health issue of major significance around the world. This disease is caused by Mycobacterium Tuberculosis (MTB), which is transmitted through the air or by ingesting infected milk or meat (Bovine TB) and it is both preventable and curable (Caminero, 2008). It affects the lungs (pulmonary TB) but can also affect other organs for instance the extra pulmonary. Pulmonary tuberculosis patients can infect other people through droplet infection, which can occur when they sneeze, cough or talk (World Health Organization, 2006). TB prevalence among the close contacts of a patient who is infectious can be 2.5 times higher than prevalence in the general population (Lemos, Matos, Pedral-Sampaio , & Netto, 2004).

The World Health Organization (2015) estimates that globally in 2015 there were 10.4 million new cases of TB, of which 5.9 million (or 56%) were among men, 3.5 million (34%) among women and 1.0 million (10%) among children. People living with HIV accounted for 1.2 million (11%) of all new TB cases. Kenya is one of the 22 World Health Organization defined high burden countries where 80% of the world's burden for TB exists; it is 13th amongst the 22 high burden TB countries (Billingsley, Smith , Shirley, & Keiser, 2011). TB is underreported and furthermore TB-related morbidity, mortality and drug resistance are expected to increase (Ayisi et al., 2011). The Estimated number of new TB cases in Kenya is around 107,000 (WHO Report, 2016). Estimated TB prevalence in Kenya is around 300/100,000 (Infectious Diseases Kenya, 2009).

The invention of Internet and of the Word Wide web offers great opportunities of revolutionizing people's lives. Health care settings are increasing employing Information technology, which offers significant contribution in providing health care services by aiding cut costs and improving quality of health care (Blaya , Fraser , & Holt , 2010). In 2005 WHO passed a resolution, which enables member states to achieve collaboration and provision of mutual support in health systems integration aiming in improving health care, supporting surveillance activities and sharing knowledge (Simba, 2004). With more people connected to the internet, which is available and reliable, this can be achieved. TB control programs that use mobile and web-enabled applications

provide a great potential for significantly improving TB service provision along with harnessing the benefits for the global fight against TB.

Contact tracing is regarded as effective strategy to identify recently infected individuals and has become an essential component of the tuberculosis (TB) control strategy in most low and middle-income countries (Volkmann et al.,2016). In contact tracing, every index case is asked to name his or her contacts in other terms graphing neighbors who may be infected, then the public health official seeks out these contacts as time and resources permit to screen or test whether they are infected and treat them if so (Armbuster & Brandeu, 2007). TB contact tracing in general aims to identify individuals with TB disease or Latent TB Infection (LTBI) among the contacts of a TB patient and providing adequate treatment or follow-up, reducing morbidity and mortality due to TB among newly infected individuals and reducing further transmissions. Contact screening complements efforts of contact tracing. This process follows risk stratification concerning the infectiousness of the index patient, the duration and proximity of exposure, and the susceptibility of the contact. More important the screening includes evaluation for possible TB disease with a symptoms questionnaire (e.g. cough, chest pain, fever, night sweats, appetite loss or weight loss) and chest radiography (Erkens , et al., 2010) .

Traditional Contact tracing and screening activities can be supported by modern information technologies through use of mobile phone and text communication with possible TB contacts. The ability to rapidly collect and access high quality data presents a notable benefit since the aim of TB contact tracing and screening is to disrupt the spreading of the disease and timely inform disease control efforts (Chapman, Darton, & Foster, 2013). Internet-based partner notification involving use of email in initiating contact is a classic example of use of internet technologies in contact tracing. Electronic patient Registers have successfully been used to improve TB surveil-lance. In Massachusetts, USA, Electronic patient registers have been successfully set up to further improve TB surveillance by helping to identify TB patients being started on anti-TB regimen who had not been notified as new cases. A system was incorporated, where the Electronic Patient Register raised an alert in a predefined scenario, for example when doctor prescribed to a patient TB drugs, when a patient samples were sent for TB culture, or when a patient had laboratory test result that suggested he had active TB. This improved the efforts of contact tracing by presenting

accurate reports of active cases, hence contributing to more comprehensive and rapid identification of potential contacts (Calderwood , Platt, & Hou, 2010).

Despite these advancements in technology that can improve TB Contact tracing and screening, the National TB program in Kenya has fallen short in adopting them. It is on this note that the study is undertaken to establish an effective and efficient way of TB contact tracing and screening using mobile technology. The study aimed at incorporating USSD and Android technology in contact tracing and screening activities in order to target a larger group and improve TB contact tracing, and screening in Kenya.

1.2 Problem Statement

The National TB program is facing significant challenges as it relates to combating TB. The challenges identified include; inadequate personnel, inability to cover vast geographical locations, inefficiencies in data collection and reporting and low surveillance of TB patients and their contacts. Because of these challenges, the TB rates in the country have recently (MoH Kenya, 2015). In Kenya, Healthcare workers conduct TB contact tracing by visiting cases' homes and using a national TB contact tracing paper form to screen household contacts. Health care workers record contacts' responses directly onto the paper form and later enter these data into a Microsoft Excel database by hand. These data are also used to generate summary reports.

There may be considerable limitations to conducting TB contact tracing with this approach in Kenya and other resource-limited settings. For example, the use of paper forms may result in inefficiencies in data collection, storage, and retrieval and errors (e.g., missing, incorrect, or illogical values). In addition, summary reports must be generated by hand. This process is not timely and can take a significant number of days before the limited number of health workers are able to trace and screen contacts in different places. This dissertation sought to develop a USSD and Android based system for TB contact tracing and screening. The system is also integrated to a web dashboard, which provides various reports and analytics from a central data store. The real time data submission to a central data store enables TB policy officials to make decisions faster and in effective manner.

1.3 Research Objectives

The main purpose of this study was to develop a mobile-based system for TB contact tracing and screening.

The specific objectives of this study include:

i. To investigate the factors relating to TB contact tracing and screening

ii. To review related architecture, models, technologies, and challenges of existing TB contact tracing and screening approaches.

iii. To develop, design and test a mobile-based system for TB contact tracing and screening.

iv. To validate the developed system.

1.4 Research Questions

i. What are the factors relating to TB contact tracing and screening?

ii. What are the existing architecture, models, technologies and challenges of existing Tuberculosis contact tracing and screening approaches?

iii. How can a mobile-based system for TB contact tracing and screening be designed, developed and tested?

iv. Can the developed system assist in TB contact tracing and screening?

1.5 Study Justification

Challenges of managing and analyzing patient data records have a significant effect in monitoring and combating effects of the disease on Kenya's socio-economic landscape. TB contact tracing and screening, adhering to treatment and collecting data remotely, are special areas that require particular attention in combating TB disease. In note of these challenges, the Ministry of Health (MoH) will greatly benefit in implementing a TB Contact Tracing system (TBCT) using mobile technology. The primary product of this study was a mobile-based system that allows tracing and screening of TB contacts. An Android application was developed for the purpose of contact tracing while a USSD application helped in the process of screening. This system also incorporated a web dashboard that presented various analytics and reports to TB policy officials in order to significantly contribute in decision-making processes.

1.6 Scope of study

Attention of this research was focused on Tuberculosis contact tracing and screening models and approaches currently in use in Kenya based on the guidelines developed Ministry of Health and international guidelines laid down by World Health Organization. Important aspects investigated and discussed included problems of the current model, possible solutions to address the problems, detailed analysis, development, implementation and testing details of the proposed solution. The target users included TB clinicians, TB contacts and TB policy officials. The deliverable of this research was a mobile-based system and a web application. This involved development of an Android application, which allowed clinicians to trace TB contacts, and a USSD application, which enabled the TB contacts to screen their symptoms and risk factors. The web dashboard allowed display and presentation of the various analytics and reports as collected from the Android and USSD applications.

Chapter Two: Literature Review

2.1 Introduction

This chapter covers the literature review. It starts by reviewing Tuberculosis contact tracing and screening, models used in tuberculosis contact tracing and screening and highlights the challenges being faced by the contact tracing and screening models and approaches. A review of the development technology is then presented. Lastly, the conceptual framework and a brief summary of the chapter is presented.

2.2 Tuberculosis Contact Tracing and Screening

The Roget's International Thesaurus (2011) defines tracing is an act of finding, tracking, trailing, following, locating or hunting down. This in simple terms means: to seek, capture or get hold of somebody. In the context of TB contact tracing and screening, tracing involves following up TB patients to identify and screen their contacts who are at risk of contracting TB (Kovarik, 2010). The process begins immediately after identifying a TB case index also known as source patient. The TB case index is identified through use of smear positive results (Kabongo & Mash, 2010). TB contact tracing serves several functions; Identification of persons with Latent TB infection or TB disease among TB patients contacts and provision of adequate and prompt follow-up and treatment (Zellweger, 2010; Mulder et al., 2011). This process also identifies and traces the contacts of contacts. This is because new TB patients may have contacts, and this contact must be found and tested for TB. TB contact tracing also helps in reducing further transmission in household and places of work. Further, it aims in reducing morbidity and mortality of TB among person who have been newly infected.

The Roget's International Thesaurus (2011) defines screening as activities that relate to selecting, inspecting, assessing, investigating examining or testing. Screening can also mean to study, research, scrutinize, analyze or review something. In the context of TB contact tracing and screening, screening attempts to find, test, treat and notify person who might be having a Latent TB infection or disease which might have been caused by being in contact with a person with the TB disease (Zellweger, 2010). Health institutions are required to screen contacts very fast and within the earliest time after they diagnose someone with TB infection.

At a national level, the decision to initiate contact tracing is based first on the ability of the National TB Programme to undertake contact-tracing activities in addition to the essential tasks of identifying TB cases and treating them successfully. Once this decision has been made, a decision to initiate contact tracing for any individual TB case is based on the level of infectiousness of the index TB case and the characteristics of the contacts (Bailey , Gerald , & Kimerling, 2002). If the index case is a child aged under 10 years, contact tracing is not recommended as children of this age rarely transmit TB. If, however, the child has sputum smear positive TB then contact tracing should be carried out (Bailey et al., 2002). A diagnosis of TB in a child usually indicates there has been transmission from an infectious adult; therefore, the objective of contact tracing for index cases who are children may be to find the source of the child's infection. This is sometimes referred to as a source case investigation and involves asking household and other close contacts if they have signs and symptoms of TB, in an attempt to find the person who may have infected the child (Dye , Maher, Weil, Espinal, & Raviglione, 2006).

2.3 Tuberculosis Contact Tracing and Screening in Kenya

The current process of TB contact tracing in Kenya follows the following narrative. When a person is diagnosed with TB, the TB clinician assists him/her to fill a form that details the people he/she has had close contact with. Example of contacts can be persons the patient works with or family members he/she lives with. More attention is given to contacts who are HIV-positive. The TB clinician then assigns community health worker to go to the community to identify trace and screen these contacts. After tracing the contacts, the community health worker is required to do screening. This entails asking them a set of TB symptoms questions. The health worker then records these responses in a contact examination form. (MoH, 2016).

It is a requirement for this investigation to start within three working days after a TB patient has been registered and identified his/her contacts. Based on the responses the contact gave, the health worker may refer them to visit a health facility for a TB test. The TB clinicians will then record the names of this TB contacts in a paper register referred to as Suspect and Sputum Dispatch register. The close contacts of a Multi-drug resistant TB patient are known to have high rates of MDR-TB and hence this should be followed up for at least a period of two years (MoH, 2016).

2.3.1 Documented Case of TB Contact Tracing and Screening in Kenya

An intervention on contact tracing and screening was developed and piloted on three facilities situated in Kisumu County. This took place between November 2014 and April 2015. The three facilities were selected for the exercise based on high TB burden and the existence of a community health strategy that was utilizing community health volunteers. The exercise was done within the Kenyan Ministry of Health contact tracing and screening program. In addition, the Ministry of Health forms were utilized without making alterations (Volkmann, Okelloh, Agaya, & Cain, 2016). A package of changes to the contact tracing process included introducing a contact tracing register and modifying practices at the facilities the study was undertaken. The register included notes from community health volunteers' notebooks, facilities' variables, facility TB register variables and variables abstracted from Ministry of Health forms.

Other components of the intervention included retaining community health volunteers on contact tracing procedures, assigning a TB clinician at each facility who had the responsibilities of making updates to the routine Ministry of Health TB register to additionally maintain the pilot contact tracing register, monthly meetings to review and update community health volunteers on their progress and compensating the TB clinicians with $ 70 (Volkmann, 2016). It was noted that this simple programmatic interventions significantly improved the effectiveness of contact tracing and screening, in an area with an existing community health strategy (Volkmann, 2016).

2.4 TB Contact Tracing and Screening Models and Approaches

This section reviews contact tracing and screening models and approaches. Important models reviewed include Electronic patient records, web-based strain typing, social network analysis, geographic information systems and mobile solutions and genomics.

2.4.1 Contact Tracing Through Use of Electronic Patient Records

Electronic patient records (EMRs) also known as Electronic Medical Records (EMRs) have widely been used in various countries over the world. Electronic Patient Records aim to improve various aspects of medical and clinical practice. This include prescription of drugs and treatment, following up patients, managing chronic diseases and ensuring that clinic guidelines are adhered to. Electronic patient records experience some challenges, which include underestimating the time commitment of doctors and clinicians, costly ongoing technical support and challenges of ensuring

that patient confidentiality is maintained (Lau et al., 2012). Attributed to the fact that Internet access, availability and reliability globally is increasing, there is a consensus that Electronic Patient Registers could contribute significantly to the activities of contact tracing.

In Massachusetts, USA, Electronic patient registers have been successfully set up to further improve TB surveillance by helping to identify TB patients being started on anti-TB regimen who had not been notified as new cases. A system was incorporated, where the Electronic Patient Register raised an alert in a predefined scenario, for example when doctor prescribed to a patient TB drugs, when a patient samples were sent for TB culture, or when a patient had laboratory test result that suggested he had active TB. This improved the efforts of contact tracing by presenting accurate reports of active cases, hence contributing to more comprehensive and rapid identification of potential contacts (Calderwood , Platt, & Hou, 2010).

Electronic Patient Registers have elsewhere been applied in improving compliance with TB screening programs especially for patients with tumor necrosis factor antagonist who were commencing biologic therapies (Hanson et al., 2013). In Illinois, USA, a system was setup, which flagged all patients under electronic prescription for tumor necrosis factor antagonist, the flagged patients were required to undergo screening for TB, hepatitis B as well as liver function tests. This approach can be extended to a wide range of settings.

2.4.2 Contact Tracing and Screening Using Web-Based Strain Typing

According to Crawford (2003), development and refinement of strain typing methodologies, when used along traditional contact tracing and screening activities, can offer a great potential for improving TB contact tracing and screening. This can be achieved by typing the Mycobacterium tuberculosis isolates according to the number of repeat sequences at various loci within the genome. The Mycobacterial interspersed repetitive units-variable number of tandem repeats (MIRU-VNTR) method is said to use 24 loci. A 24-digit code is assigned to each isolate which specifies how many repeats can occur at each locus. The codes being highly specific for that isolate are used to provide proof against or for transmission from person to person. Strain typing data enables early initiation of control measures by allowing rapid identification of potential clusters of related cases (Tardin, Dominice, & Janssens, 2009).

The development of large web-based national and international strain registries supports the utility of strain typing (Weniger, Krawczyk, Supply, Harmsen , & Nieman, 2012). Comparisons can be made easier between strains for local and wider epidemiological investigation activities (Shabbeer, Ozcaglar, Yener, & Bennett, 2012). To explore genotype-phenotype associations, databases that contain full genomic sequencing data can be used as possible research tool, a good example is *M. tuberculosis* genome divergence database, which is an open access database (Vishnoi , Srivastava, Roy, & Bhattacharya, 2008).

2.4.3 Contact Tracing and Screening through Social Network Analysis

The use of network-informed approach in TB control, particularly in identifying how TB cases are connected to each other, and how to prioritize which TB contacts should undergo evaluation was influenced by the successful use of the approach in contact tracing and screening sexually transmitted infections (Klovdahl, 2015). To examine TB clusters and outbreaks, social network methods alone and combining them with conventional and molecular epidemiology have been applied in Aboriginal settings (McElroy, Rothenberg, Varghese & Woodruff, 2016). Use of network methods have demonstrated that locations are very important in evaluating TB transmissions. Linking cases and contacts using network methods has demystified traditional expectations of how contacts interact (Cook et al., 2007). In remote communities of Manitoba, an Aboriginal community, network informed approach aided in understanding the boundaries, transmission locations and the risk of contracting TB. A network informed approach was used in investigating a TB outbreak that was developing and involved Aboriginal persons who were living on and off reserve in British Columbia, as well as a northern shelter outbreak (Cook et al., 2007).

2.4.4 Contact Tracing and Screening Using Geographic Information Systems

Geographic Information System refers to tools, which are able to visualize data that involves distances and locations. These tools have been applied in examining distribution of TB index cases, analyzing risk factors for acquiring TB disease and establishing how TB relates to surrounding environment and heath care system (Moonan, Bayona, Quitugua, Oppong & Dunbar, 2014). Immigration patterns are significant factors to TB rates in areas that have low incidence. However, research has clearly indicated that, the deprivation of certain ethnicities significantly influences TB disease rates and not only high prevalence immigration backgrounds (Moonan et al, 2014). In

Kenyan communities, there are no published studies on use of geographic information systems in curbing diseases. However, the results available today particularly that relate to determinants of health, if mapped to various locations and distances may significantly contribute in understanding the patterns of the disease among communities in Kenya.

2.4.5 Contact Tracing and Screening Using Mobile Solutions

Mobile applications are increasingly being used for contact tracing and screening activities of Ebola, TB and sexually transmitted infections. This range from USSD, Android applications, IOS applications and mobile web applications. These applications have provided the capabilities of providing electronic contact examination forms, improving data collection and reporting and capturing precise locations of contacts (Denkinger et al., 2013)

In an effort to improve on the paper form–based approach to TB contact tracing and screening, scientists from Botswana developed a mHealth approach to TB contact tracing composed of a mobile phone/tablet app and online database. This new approach was designed to eliminate the need for paper contact examination forms and writing, manual entry of data into a database, and manual generation of summary reports. The mHealth approach was also designed to enable users to capture the geographic coordinates of cases' homes. In addition, it reduced the time required to complete TB contact tracing per contact for contacts of both adult and pediatric TB cases and generated and e-mailed summary reports to designated recipients (Yoonhee et al., 2016).

This new approach also improved the quality of data collected. The application also eliminated problems arising from illegibility and prevented users from leaving fields blank or entering illogical values. Similar to other mHealth approaches that have taken advantage of the GPS functionalities of mobile devices, this new approach improved the quality of location data collected (Khan et al., 2012; Yoonhee et al., 2016; Vella, 2012).With the app, users could activate the mobile device's GPS functionality and capture the geographic coordinates of each case's home.

2.4.6 Contact Tracing and Screening Using Genomics

In improved efforts in investigating TB, some countries have employed current molecular epidemiology methods. Techniques such as RFLP/PFGE, which are simple DNA fingerprinting and MIRU-VNTR, which is an advanced technique based on sequencing, have been widely used. These methods readily allow identification of cluster of related cases but are not able to provide

further details as regards to resolution of transmissions happening individually within a cluster (Gardy, Johnston & Ho Sui, 2011).

DNA sequencing technology has experienced rapid advancement, which have enabled whole genome sequencing of bacteria quite tractable like in Mycobacterium tuberculosis. For as little like 50 dollars to 250 dollars a day, a genome is now able to be sequences and the resulting data may be used in understanding the dynamics of transmission in a much higher resolution (Gardy et al., 2011). A good example of this was carried in Canada, where genomic data from recent TB outbreak facilitated in identifying events of transmission, identify individual who acted as super spreaders and confirmed parallel related yet distinct TB outbreaks that happened within a Canadian community (Gardy et al., 2011). This was carried by integrating clinical data, genomics and social network analysis to better characterize a TB outbreak that had significantly affected this Canadian community. The investigation confirmed that social factors played a more significant role in the TB outbreak than organism virulence or ethnicity.

2.5 Challenges Faced By TB Contact Tracing and Screening Models

Several reasons for low case TB detection rates and delays in treatment have been advanced and attributed to limitations of contact tracing and screening models. A report by WHO says the main challenges include; inadequate personnel, inefficiencies in data collection and reporting and low surveillance of TB patients and their contacts. Challenges of managing and analyzing patient data records have a significant effect in monitoring and combating effects of the disease on Kenya's socio-economic landscape. TB contact tracing and screening, adhering to treatment and collecting data remotely, are special areas that require particular attention in combating TB disease.

Kenya contact tracing and screening model compare to that of Botswana, in that manual and paper based methods are used in collecting tracing and screening data and in managing patients. A number of challenges faces this approach; first being shortage of health personnel - Kenya has a high health worker shortage, mostly affecting the rural areas. Most health workers are employed in the private sector, in which the competition for doctors drives the costs of healthcare (Kenya health sector care report, 2016). This inadequate health labor force is itself overwhelmed by other core responsibilities.

Time and travel costs – Some parts of the Kenyan rural areas are sparsely populated especially the Northern part. Population density ranges from one or two (people per sq. km) in parts of Turkana and Marsabit (Kenya Population and Housing Census, 2009). This implies that this inadequate workforce is required to cover long distances to locate and monitor TB contacts. Travelling is expensive and consumes a lot of time.

Poor data records and distribution- The capturing of data of TB contacts is carried using paper documents. The health workers then present these papers documents to data clerks at the health facility who then transfer the data into a database (MoH, 2016). This approach results into poor data records especially when some paper records go missing before they are keyed into the database. The information stored in these databases is also not centralized which means that this data can only be accessed from a single location.

Analysis of data – The system being paper based and having poor data records and distribution poses significant challenges in accurately analyzing data used in creating reports and making decisions. In addition, human errors encountered in keying the data further makes it difficult to produce accurate analyzed data.

2.6 Documented Contact Tracing and Screening Systems

Several contact tracing and screening systems are presented and analyzed focusing on the architecture and highlighting the similarities and differences. The limitations of these systems are also noted.

2.6.1 USSD TB Contact Tracing and Screening System in Botswana

This system was developed in Botswana to aid in TB contact Tracing and screening. The system incorporates a USSD interface for use by the TB contacts and web interface for use by the community health workers. Data is collected from TB contacts using short questions after the TB contact dials a USSD code. This data is then stored in a relational database. From the responses of the TB contact, the system decides whether to refer the TB contact for a TB test. The system also allows community health workers to carry out follow-ups with contacts who were referred so as to ascertain if this contacts went for a test or not and also to ascertain the status of their TB tests. The web dashboard allowed community health workers to create and view reports submitted by the TB contacts (Makhura et al., 2014).

Different devices and uses interacted with the system through use of multiple interfaces. GSM networks allowed mobile phones users to interface with the system. This involved use of USSD protocol to facilitate communication with the system. This allowed sending of messages to through the USSD gateway to the server. The USSD gateway also allowed passing of information from the database server to the GSM mobile devices. The main challenge with this system is adapting it to meet different countries requirements as it relates to contact tracing and screening (Makhura et al., 2014). Figure 2.2 shows Botswana's USSD TB contact tracing and screening architecture.

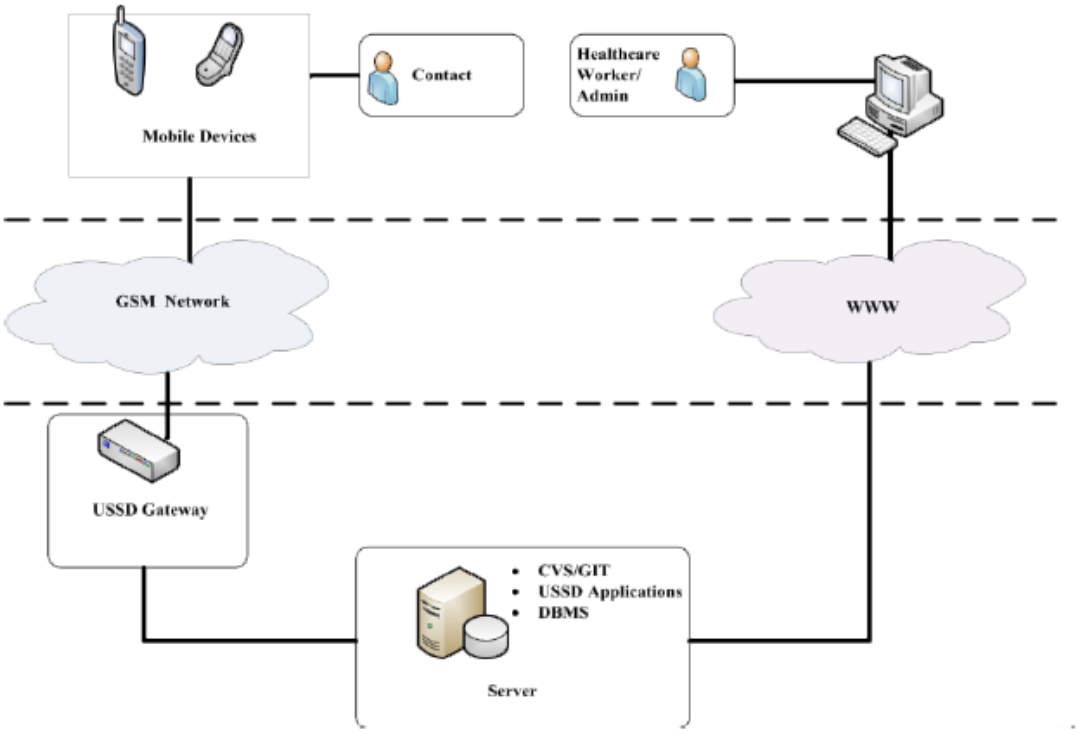

Figure 2. 1 Botswana's USSD TB Contact Tracing and Screening Architecture

(Adapted from Makhura et al., 2014).

2.6.2 Electronic Tb Contact Tracing and Screening on a Large Scale in China

Tuberculosis surveillance in China is organized through a nationwide network of about 3200 disease control centers or TB dispensaries. In order to replace paper recording, a nationwide electronic Tuberculosis Information Management System (TBIMS) started to be phased in 2005. Since this time, the system has evolved, into a more elaborate system that aids in collecting key information of TB index cases who have been notified, confirmed or still undergoing evaluation

in care facilities. The system also allows real-time exchange of data with Infectious Disease Reporting system, covering the country's 37 notifiable diseases. The system achieved countrywide coverage by 2009 (WHO, 2015).

In the phased development, TBIMS ran in parallel to a paper-based surveillance system from 2005 to 2008. The paper-based surveillance system was discontinued in 2009, after the diminishing of difference between cases captured in the two systems and ability of TBIMS to capture almost all TB cases notified. TBIMS is password protected and is accessible to authorized users at every level of the TB network. A cascade approach was used in training the users on the system, this involved first training Health personnel at provincial and prefectural TB health facilities who in turn trained the other worker at county level. What makes TBIMS stand apart from the TB electronic information system adopted by other countries is sheer scale of the data it can handle and the intricate functions it is able to perform. The main limitation of this system lies in customizing it to meet the different guidelines of contact tracing in different countries. Figure 2.2 shows China's Tuberculosis Management System Architecture.

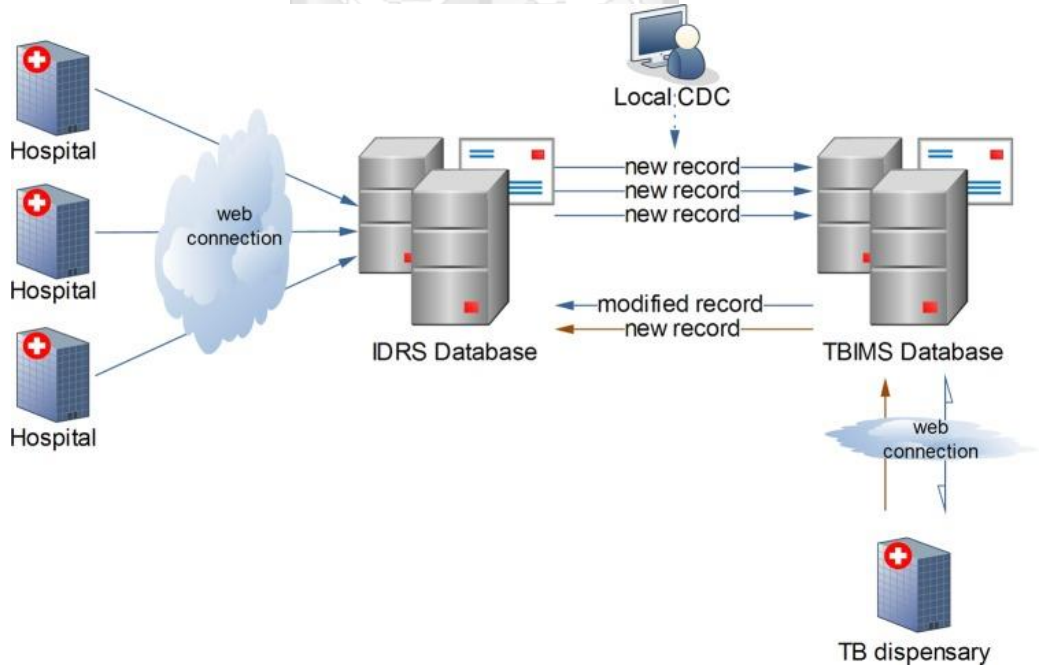

Figure 2. 2 China's Tuberculosis Information Management System Architecture

(Adapted from WHO Report, 2015)

2.6.3 A Comprehensive Web-Based Tool for Programmatic Management of TB

Through a USAID- funded programme, Management Sciences of Health was able to create a system they named e- TB Manager. The web-based system was developed with aims of centralizing diagnosis information, treatment information, laboratory use information and medicine prescriptions. The software architecture of e-TB Manager involved, a MYSQL 5.6+ database, a JBOSS AS 4.2.3 GA application server and programming language adopted was Java 1.6+ using JEE 1.5 (Management Science of Health, 2008).

Indicators were generated by the system based on the activity data of laboratory use, medicines, treatment and diagnosis. Management Science of health supported the deployment of e-TB Manager in over 2500 sites with locations in ten countries in Latin America, Eastern Europe and Africa. The system could store close to 400000 records of patients in individual format from all the sites. A requirement for information systems, and in this case electronic patient registers is the ability to regularly and carefully update data to serve the need of its clients. Experience in using e-TB Manager showed that the investment bore substantial gains, for example, it was able to reduce the time supervisors needed to spend in collecting data on site, and hence it freed time for them to devote to other aspects of programme monitoring. Infrastructure was identified as the main limitation of the system hence there was a need to develop PC-based provincial databases (Management Science of Health, 2008). Figure 2.3 shows a snap shot of case search results page of e-TB manager.

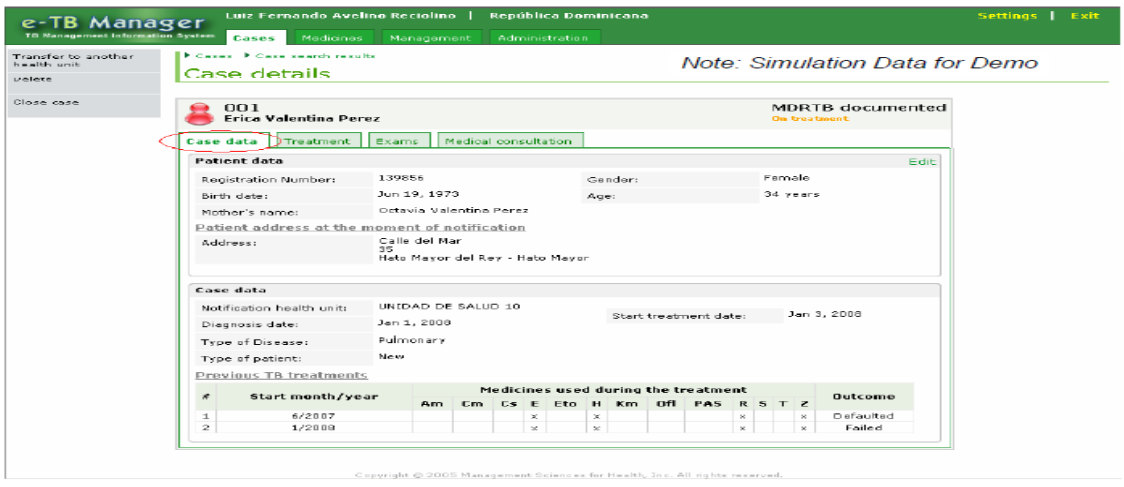

Figure 2. 3 e-TB Manager

(Adapted from Management Science of Health, 2008)

2.7 Review of Software Development Technologies

This section seeks to review the mobile technology, which was used to develop the proposed solution. This includes a review of USSD technology, its architecture and need of the technology.

2.7.1 USSD Technology

Unstructured Supplementary Service Data (USSD) is a Global System for Mobile (GSM) communication technology that is used to send text between a mobile phone and an application in the network (Rouse, 2007). The maximum length of USSD text messages is 182characters. For a USSD application to connect to the GSM network, a USSD Gateway in required. The gateway enables delivery of USSD messages of up to 182 characters on a network between mobile stations and applications. Quirk defines a USSD gateway as "the automated system that bridges the gap between mobile handsets and IP based systems and finally connects to the portal which retrieves the information requested" (Quirk, 2011).

A user accesses a USSD application by entering a short code or text strings (e.g. *100#) which triggers certain services in a session based communication. The short codes could perform a function, request a snippet of information, or lead the user into a series of textual menus that are navigated through the corresponding menu numbers. The asterisk (*) and hash (#) codes are much like simple programming codes, signifying the beginning and end of the request (Quirk, 2011). USSD is session-oriented, which implies that a session is established every time a user uses a USSD service and the radio connection stays open until the user, application, or time out releases it. This provides faster response times for interactive applications. This level of interactivity is what most users need and want when using a mobile application.

2.7.2 USSD Architecture

According to Sanganagouda (2011), the USSD architecture comprises the network part that which includes the Home Location Register (HLR), Visitor Location Register (VLR), and MSC. Another component is Complex logic to support multiple applications within a single USSD platform. SMPP (Simple Messaging Peer-Peer) interface for applications to enable services is the third component. Finally, the USSD Gateway and all specific USSD application servers.

USSD center (USSD Gateway) is entirely open and can be incorporated with any telecom system/device and the internet. These structures enable rapid deployment of new services and

inspire existing messaging applications to leverage the USSD technology. Additional elements of the USSD architecture comprise: Data Records (CDRs), a rating platform/billing system to rate the post-paid Call, Management Information Systems (MIS), IN for pre-paid billing, Data Warehouse (DWH) systems for reporting and reconciliation. Data Records (CDRs) generated at USSD Gateway can also be used for these purposes. They may be interconnected with SMSC that can be used to send notification or special SMS to users. The figure below illustrates the how USSD architecture is implemented. Figure 2.4 illustrates the USSD Architecture.

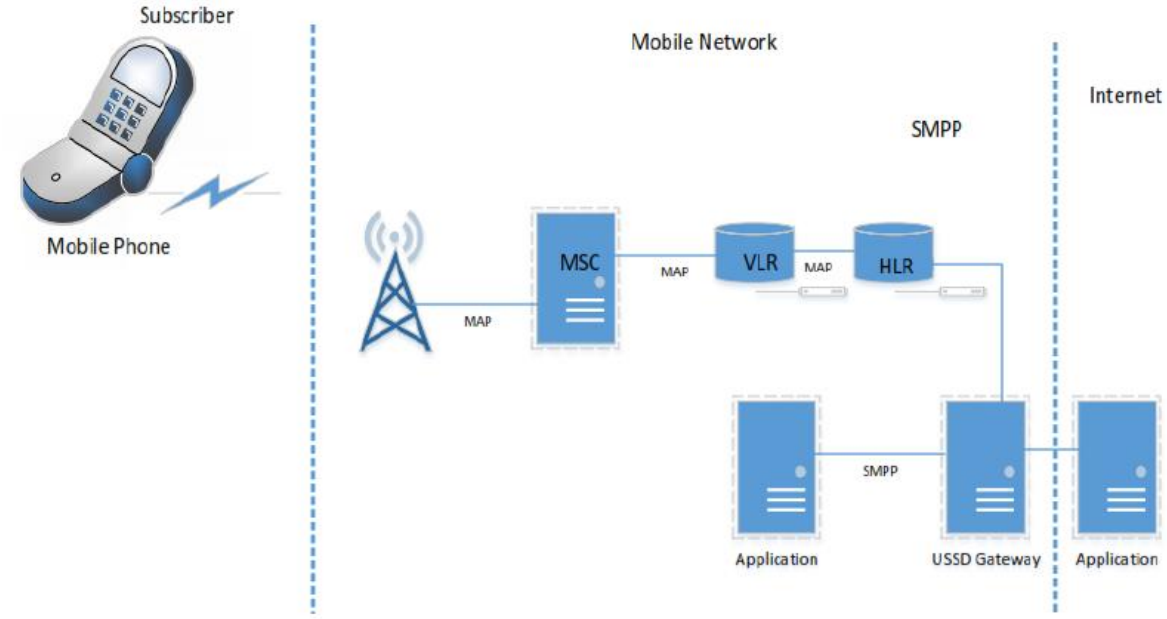

Figure 2. 4 USSD Architecture

(Adapted from Tata Teleservices Ltd, 2007)

2.7.3 USSD vs. SMS

USSD is similar to Short Messaging Service (SMS), but USSD transactions occur during the session only. With SMS, messages can be sent to a mobile phone and stored for several days if the phone is not activated or within range (Rouse, 2007). In other words, USSD is session-oriented while SMS is a store-and-forward, transaction-oriented technology. However, USSD has the disadvantage of difficulty in remembering the short codes by users especially when different services use different codes. USSD and SMS services are accessible to all users using any mobile phone device including feature phones and Smartphones

2.8 Conceptual Framework

Figure 2.5 illustrates the conceptual framework. The system has two interfaces the TB contact USSD application and the TB clinician Android application. The process of TB contact tracing and screening starts with the TB clinician indexing the contacts from information provided by TB patients. Once a TB contact is indexed, he /she is notified through a third party SMS to dial a USSD code so that he may be screened and further advised. The TB contact then selects the symptoms and risk factors. This are submitted to the application server, which has triage algorithm and advises the TB contact the action to take by sending a SMS through the USSD gateway. A TB contact may be advised to visit a TB clinic for prompt evaluation, which can include a laboratory test. The TB clinician can then record the lab results of the TB contact interpreting them as either positive or negative. All data collected is stored in a MySQL database. The application server also presents analytics to TB policy officers.

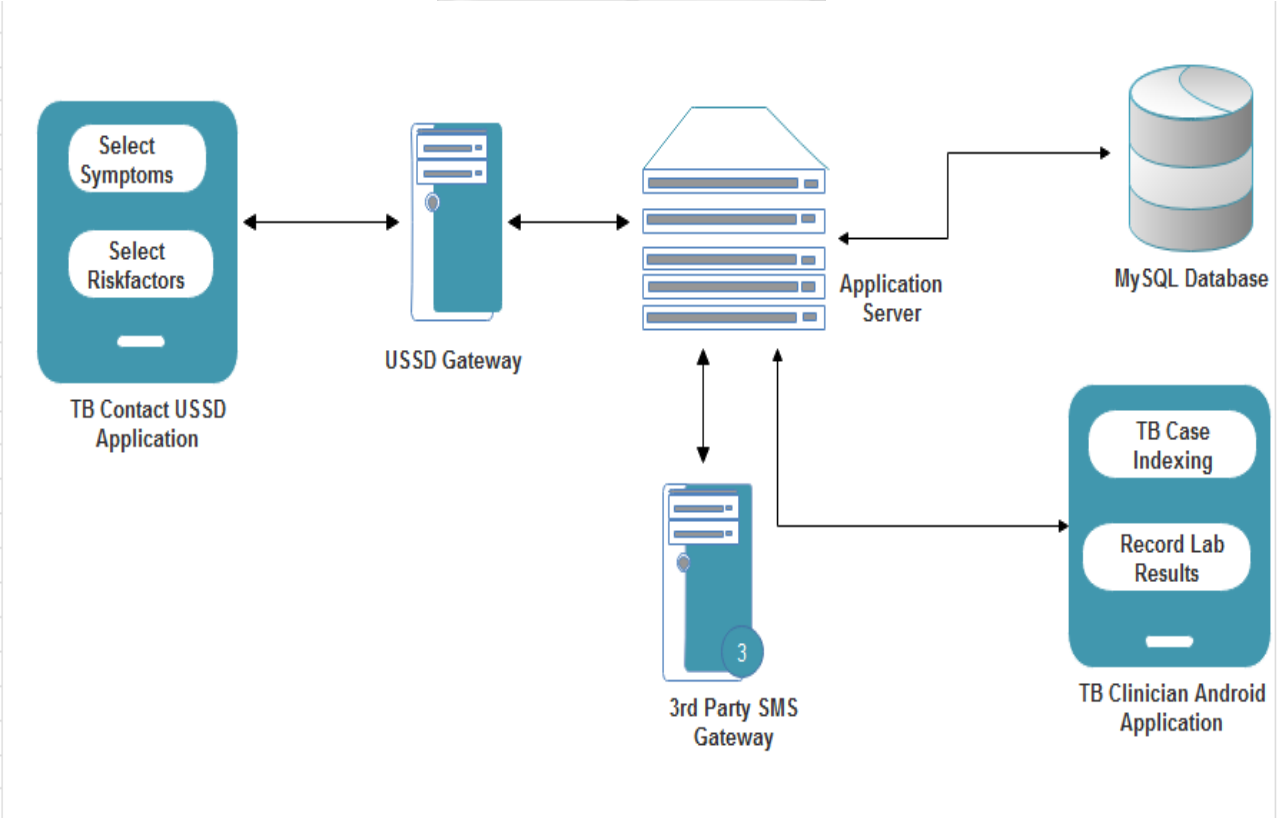

Figure 2. 5 Conceptual Framework

2.9 Summary

The existing model of contact tracing in Kenya is without a doubt challenged. While the rest of the world is embracing web and mobile technologies in combating tuberculosis, the National TB program is still gravely paralyzed. Several reasons for low case TB detection rates and delays in treatment have been advanced and attributed to limitations of contact tracing and screening models. A report by WHO identifies the main challenges as; inadequate personnel, inefficiencies in data collection and reporting and low surveillance of TB patients and their contacts. A mobile-based system can help in eliminating some of this challenges identified.

Chapter 3: Research Methodology

3.1 Introduction

This chapter presents the software development methodology that was used to design the mobile-based contact tracing and screening system. It then proceeds to discuss the research methodology used in carrying out the research in line with the research questions. The researcher also discusses how data was collected with reasons as to why these particular models of data collection were applied.

3.2 Software Development Methodology

The system methodology that was used in developing the TB contact tracing and screening system was Agile Methodology. Agile Development methodology allowed flexibility in integrating user requirements due to its incremental and iterative nature. Design, testing and implementation were done throughout the project cycle. The fundamental concepts to agile development are simple design principles, large number of releases in a short time frame, extensive use of refactoring, pair programming and testing during development (Boem & Turner, 2003). Agile development of the system followed five main phases, which include the Planning phase, Requirement analysis phase, Design phase, Building phase and the Testing phase. Figure 3.1 illustrates the Agile Methodology.

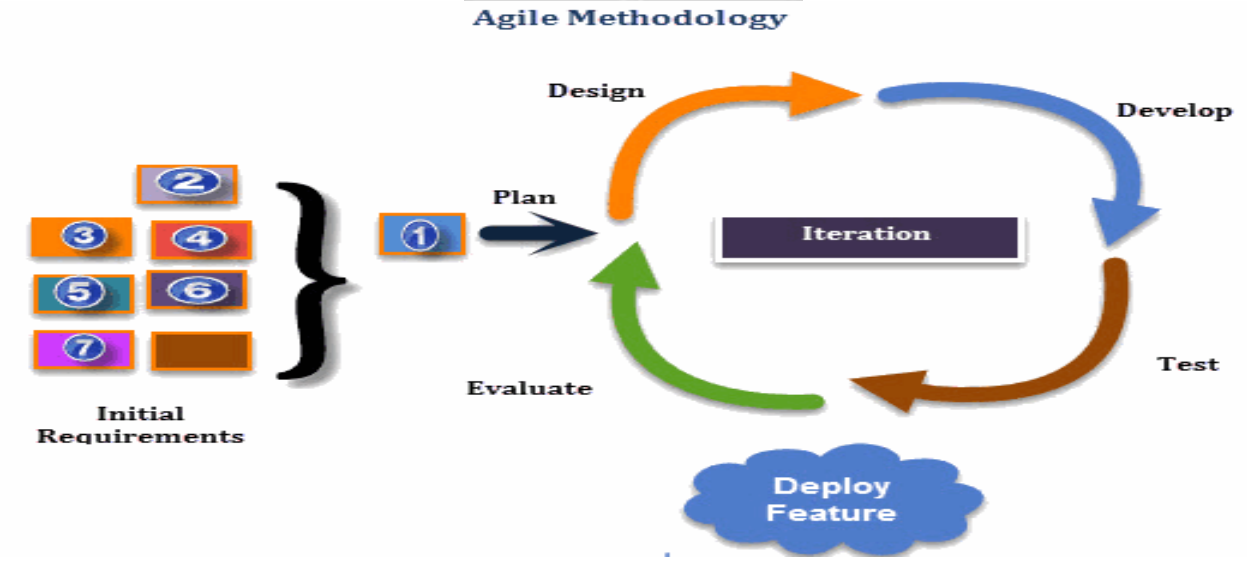

Figure 3. 1 Agile Methodology

(Adapted from Sigma, 2017)

3.2.1 Planning Phase

This is the first phase of the methodology and its core function is to enable planning of how the entire process will be undertaken (Highsmith, 2011). In this phase, the researcher defined the problem, produced a project schedule, confirmed the project feasibility, staffed the project and launched the project. This involved conducting a feasibility study to find out the scope of the problem, determining the solution and planning for resources, costs and time.

3.2.2 Requirements Analysis Phase

This second phase involved analyzing the requirements of the system and what was expected of the system. Requirements analysis were used to reveal important information like what the client wanted, tools needed to develop and test the application and what was needed to make the development process a success.

a) Location of the study

The study was carried out within the County of Nairobi. The area was selected for study due to presence of necessary resources (facilities and people) which were instrumental in acquiring data required to complete the project in time.

b) Target Population

The target population is the group of elements to which the researcher wants to make inference (Fricker, 2013). The target population was drawn from caregivers involved in TB contact tracing and screening. In order to get to reach the caregivers, the researcher visited the TB clinics and health facilities involved in managing and treating TB disease.

c) Sampling Strategy

The researcher used convenience-sampling technique. Individuals were chosen as subjects to be interviewed for the study. This technique aided in focusing on the population that was most expected to offer great insight in the development of the system.

d) Sample Size

The sample size was based on a selected number of caregivers involved in TB contact tracing and screening. The sample size from which data was collected was 40. This sample size comprised respondents of mixed gender, age, educational level and task duties.

e) Data Collection

Data collection was conducted through data inventorying, interviews questionnaires and observation. The questionnaire was structured, open ended and close ended.

i) Data Inventorying Technique

The researcher started by making an inventory of all the data flows as well as the data processes associated with TB contact tracing and screening forms. This involved identifying the flows carrying these data from their point of capture to their point of usage and then identifying the processes associated with or applied to such data. The two forms at Appendix A aided in getting precise information on the requirements of the system and further understanding the problem.

ii) Interviews

Interviews were carried out at some selected health facilities within Nairobi County to collect information regarding the efficacy of the existing TB contact tracing and screening approach.

iii) Questionnaires

Questionnaires are special-purpose documents that allow facts to be gathered from a large number of people while maintaining some control over their responses. A questionnaire was drafted and issued to TB caregivers inorder to further understand the challenges experienced with the current TB contact tracing and screening approach, the demand and to gain more clarity on the requirements of the system. The questionnaire at Appendix B aided in achieving this purpose.

3.2.3 Design Phase

The design of the system was done after the requirements analysis was complete. This guided the researcher to understand what was needed to analyze data flow systematically, process data, store data and output information in context of the study. Unified Modelling Language (UML) method was used for modelling and designing diagrams to offer a clear picture of the system developed. The study employed four different UML diagrams for its design. These diagrams included a use case diagram, database schema, sequence diagram and a design class diagram.

Use cases were used to identify and separate system functionalities in terms of who will be responsible for what, thus coming up with actors and uses cases. The actors of this system included TB patients, TB contacts, clinicians, TB policy officials and the system administrator. The use case was also represented in text to describe the action performed by the actors on the system.
The sequence diagram was used to show interaction between the objects. This gives a clear picture of how the system flows from one point to another (Object Management Group, 2005). A database design was also generated out of the entity relationship diagram (ERD) that showed the various entities and their attributes and how they are related to one another (Object Management Group, 2005).

Wireframes were designed using an online platform known as Balsamic, as it is simple to use yet very powerful with all the necessary features already provided free. This allowed the developer to have a clear view of how the interfaces looked like in terms of the total user experience.

3.2.4 Building Phase

This was the actual implementation of the designs carried out on the previous phase. The database was created from the Entity Relationship Diagram (ERD) to bring out all the tables and their relationships. The designed mock-ups were transformed into the actual system and the functionalities added.

Prototype Development

This involved coming up with a USSD application, an Android application and a web application all connected to a central remote database. The application development environments that were employed are:

a) USSD Application

The platform for application implementation for the TB contacts was a USSD and web portal connected to a central database. PHP was be used to develop the USSD Application. The web portal was developed using Laravel 5.2 and hosted on an online apache HTTP server. PHP was chosen because it is fast and platform independent (Sakshay, 2013).

b) Android Application

The platform for application implementation for the TB clinicians was an Android application connected to a central database. Android programming languages were used in the development of this application.

c) Database

The database was implemented using MySQL Database Management System (DBMS). The reason for MySQL database is because it is simple to implement and there is plenty of documentation on it.

3.2.5 Prototype Evaluation and Testing Phase

The prototype consisted of the following tests to find out whether it met the specified goals of this dissertation:

i. Usability Tests: this test were carried out on the developed application to measure user satisfaction and collect feedback for refining the prototype. The questionnaire Appendix C was used to measure user satisfaction and collect feedback.
ii. Functionality Tests: functionality tests were carried out to determine whether the system design and its implementation was a success or a failure. Test cases were derived to comprehensively test key mobile and web application components. The test results were evaluated based on Item Pass/Fail Criteria.
iii. Compatibility Tests: compatibility test was performed on different versions of mobile and web-based applications on different Android based platforms and browsers respectively. Chrome browser, Internet explorer and Mozilla browser were used.

3.3 Ethical Issues

Research ethics is critical since it guides the interactions with people, organizations and institutions. The research sought authorization for data collection from institution and participants by explaining the purpose and important of the study. Privacy and confidentiality was employed to ensure that the data collected from respondents was kept safe, free from interference and protected from unwanted use.

Chapter 4: System Design and Architecture

4.1 Introduction

The main purpose of this study was to come up with an effective system for TB contact tracing and screening. Object oriented analysis and design were used in this research. This chapter is based on data analysis, system analysis and system design. The three are discussed in detail throughout the chapter with data analysis focusing on the data collected from the sample population. System design and architecture involved the design of the system architecture and outlining the various requirements needed for the implementation of the application. This involved the presentation of sequence diagrams, use case diagrams, entity relationship diagrams (ERD), design class diagrams and wireframes.

4.2 Results from Questionnaire

This section presents the analysis of results from the questionnaire issued to caregivers who are involved in TB contact tracing and screening. 40 questionnaires were issued to the respondents; from this, 38 questionnaires were returned dully filled. Hence, the response rate was 95%. The results are presented in pie charts and clustered bar charts.

4.2.1 Age Group of Respondents

Figure 4.1 shows the age group of the 38 respondents. Majority of the respondents (65%) are in the age group of 25-34. 26% of the respondents are in the age group of 35-54, 5% are in the age group of 18-24 while 4% of the respondents are in the age group of over 54 years.

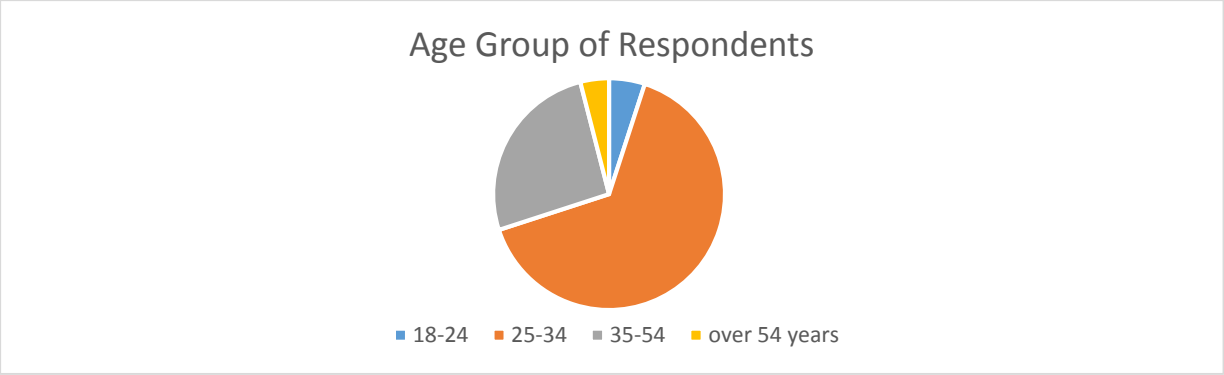

Figure 4. 1 Age Group of Respondents

4.2.2 Number of Contact Tracing and Screening Activities Undertaken

Figure 4.2 shows the number of contact tracing and screening activities the 38 respondents have been involved in. 88% of the respondents indicated that they have been involved in more than three contact tracing and screening activities, 7% of the respondents indicated that they have been involved in exactly three contact tracing and screening activities, 3% of the respondents indicated that they have been involved in two contact tracing and screening activities while 2% of the respondents indicated that they have been involved in exactly one contact tracing and screening activities.

Figure 4. 2 Number of Contact Tracing and Screening Activities

4.2.3 Contact Tracing and Screening Systems in Use.

To gain knowledge on the types of contact tracing and screening systems in use, respondents were asked to select the type of contact tracing system at their health Facilities. Figure 4.3 shows the responses of the 38 respondents. Majority of the respondents representing 92% indicated that they use paper forms along with a MS-Office application while 8% indicated use of paper forms only. There was no reported use of a mobile-based system. This implied the inherent gap. Figure 4.3 presents these results.

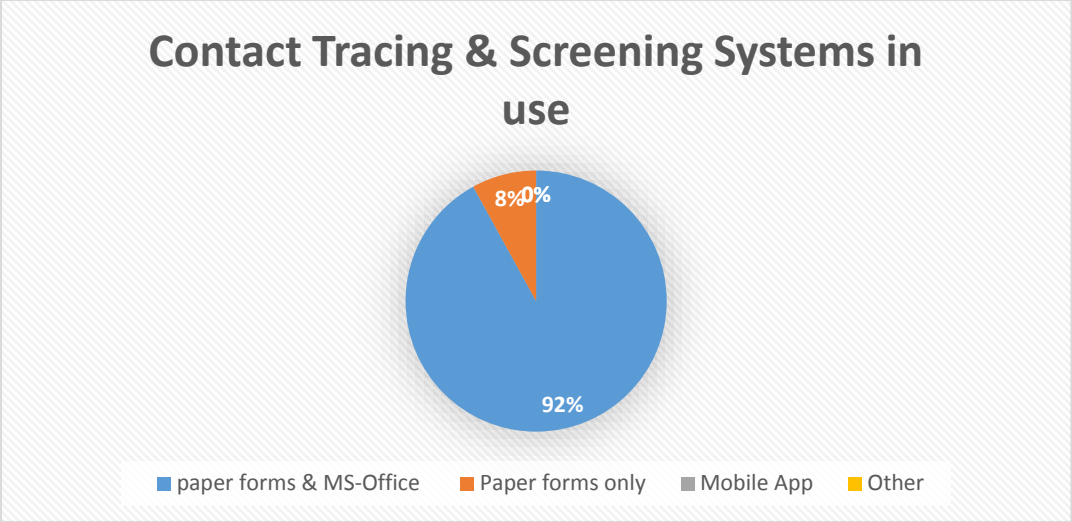

Figure 4. 3 Contact Tracing And Screening Systems

4.2.4 Need for a Contact Tracing and Screening System

In order to understand the need for a contact tracing and screening system participants were asked to list the needs of a contacts tracing and screening system. The identified needs includes; identification of contacts with positive symptoms so as to begin their treatment early, to reduce further infections, to plan TB control, to notify TB cases early and to adhere to TB control strategies. Figure 4.4 presents these results of the 38 respondents.

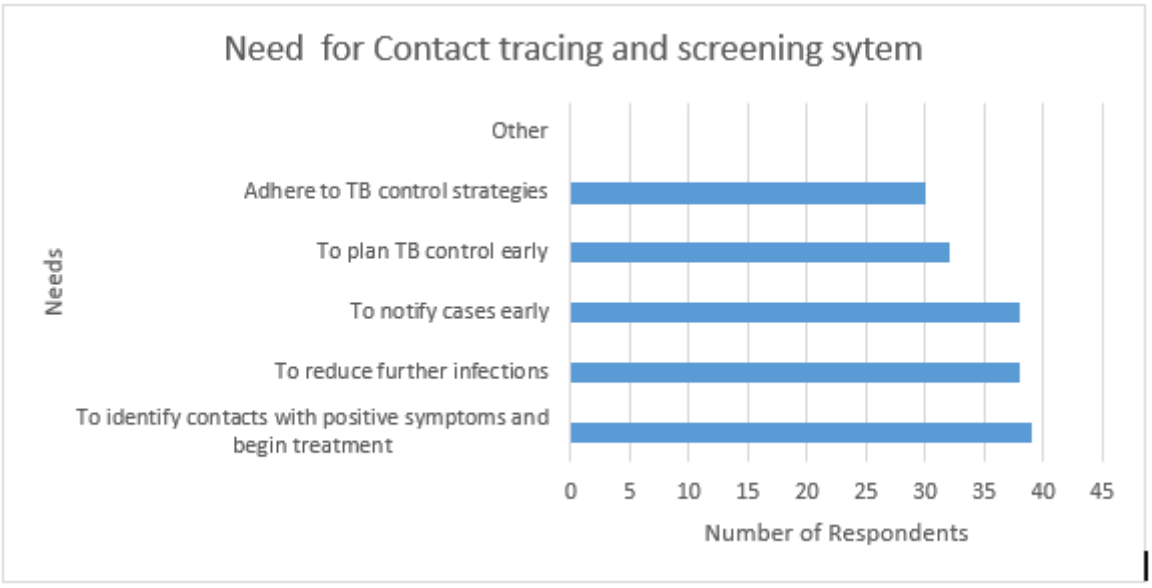

Figure 4. 4 Need for Contact Tracing and Screening System

4.2.5 Limitations of the Current Contact Tracing and Screening System

In order to better understand the limitations and shortcomings of the current system, respondents were asked to list the limitation of the current system. The limitations identified include; centralization of data, report creation, data analysis, data and record distribution. Figure 4.5 presents the results of the 38 respondents.

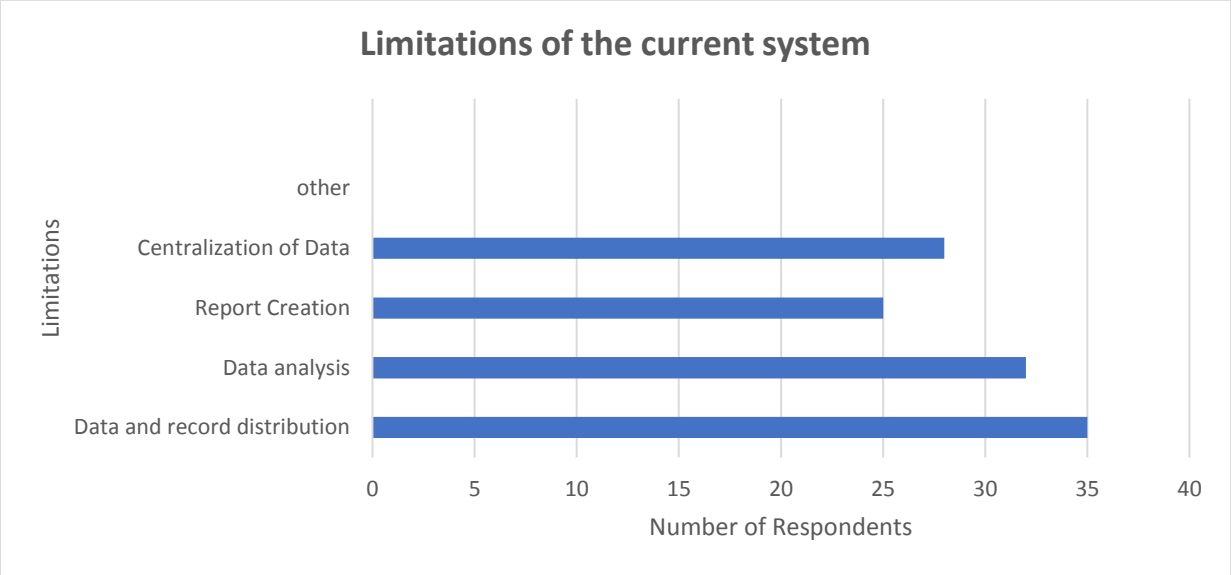

Figure 4. 5 Limitations of the Current System

4.3 Results from Data Collection and Analysis

The responses received from the respondents were highly valuable and very informative in making the decision of whether to the proposed system was feasible. The features of the system were refined based on the feedback collected by the researcher. The findings that were derived from the respondents were; the proposed solution would be feasible for TB contact tracing and screening. It was evident that developing the application in USSD would enable majority of contacts to access the service, therefore it was most preferred platform for development of the front-end application. It was also evident that developing an Android application would enable the TB clinicians to timely index, alert these contacts so that they could be symptom screened for TB, and thereafter record their laboratory results after they took tests. The WHO forms in Appendix A along with the responses from questionnaires and interviews were very useful in coming up with the system requirements that aided in designing the system and in the implementation process.

4.3.1 Functional Requirements

The functional requirements are the basic processes, capabilities and functions, which the system implemented is required to execute. The functional requirements for the system included:

i. Select Symptoms- users are able to select their symptoms
ii. Select risk factors -users are able to select their risk factors
iii. Screen the TB contacts -The system is able to advice the TB patients what actions to take based on combinations of their risk factors and symptoms
iv. Capture Laboratory Results- The TB clinician is able to record the laboratory test results of contacts confirming they have TB or not.
v. Manage services - The administrator is able to add, delete or update a service.
vi. Check analytics -The administrator, caregivers and TB policy officials are able to view the summary of TB results of the contacts.
vii. Notify users- informs indexed contacts through SMS to dial the USSD short code for screening and also informs them of next steps after screening symptoms.

4.3.2 Non Functional Requirements

Nonfunctional requirements describe the qualities that a system can function without, but are necessary to ensure that the system is friendly, easy to use and interactive. The first is Security, the web backend app has administrator who must have authorized usernames and passwords to view all the system. In terms of reliability, the application should have minimal failures with fast recovery of the experienced failures or delays. Availability was needed to ensure that the application must always be readily available for the user during any circumstance so that there are minimal failures. Usability is also key, the application should be easy to use and interact with. The application should provide seamless and fully unified experience. Navigation in the USSD to ensure that users should easily navigate through the Menus before session times out. Navigation in the Android application to ensure that the TB clinicians navigate without need of assistance. Navigation also in the Web Application, whereby the links point to their respective pages to ensure smooth navigation between the pages without any problems or abrupt disconnections.

4.4 Design Phase

This section was used to explain the design and architecture of the system developed as a proof of concepts. A database was used and the database schema will be discussed below as well as the UML diagrams used to further design the system and show how the user interacts with the system.

4.4.1 System Architecture

The proposed system involves two front-end applications, which are the USSD application and an Android application. It also consists of a SMS gateway, back-end web application and a database. The front-end user of the Android application is the TB clinician who indexes the TB contacts and alerts them to dial USSD code through the SMS gateway. The front-end user of the USSD application (TB contact) can then register, select symptoms, select risk factors and check screening results. The database stores the responses of the user and presents them to the application server. The application server processes the symptoms and the risk factors and sends a message on action to take to the TB contact through the SMS gateway. The application server further presents the analytics through a web application in the form of tables and charts. Figure 4.6 illustrates the proposed system architecture.

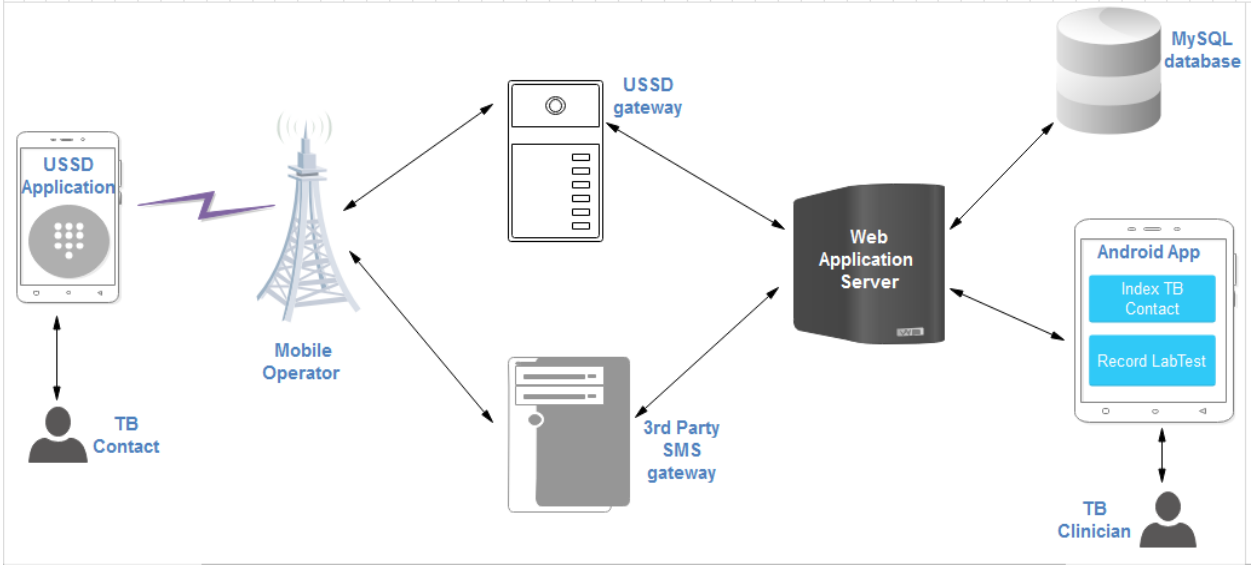

Figure 4. 6 Proposed System Architecture

4.4.2 Sequence Diagram

The sequence diagram in Figure 4.7 shows the flow of events as the TB contact wishes to be screened for TB. This is represented by flows from the user, the USSD application, the USSD menu, SMS carrier, TB clinician, Android application and the application back-end.

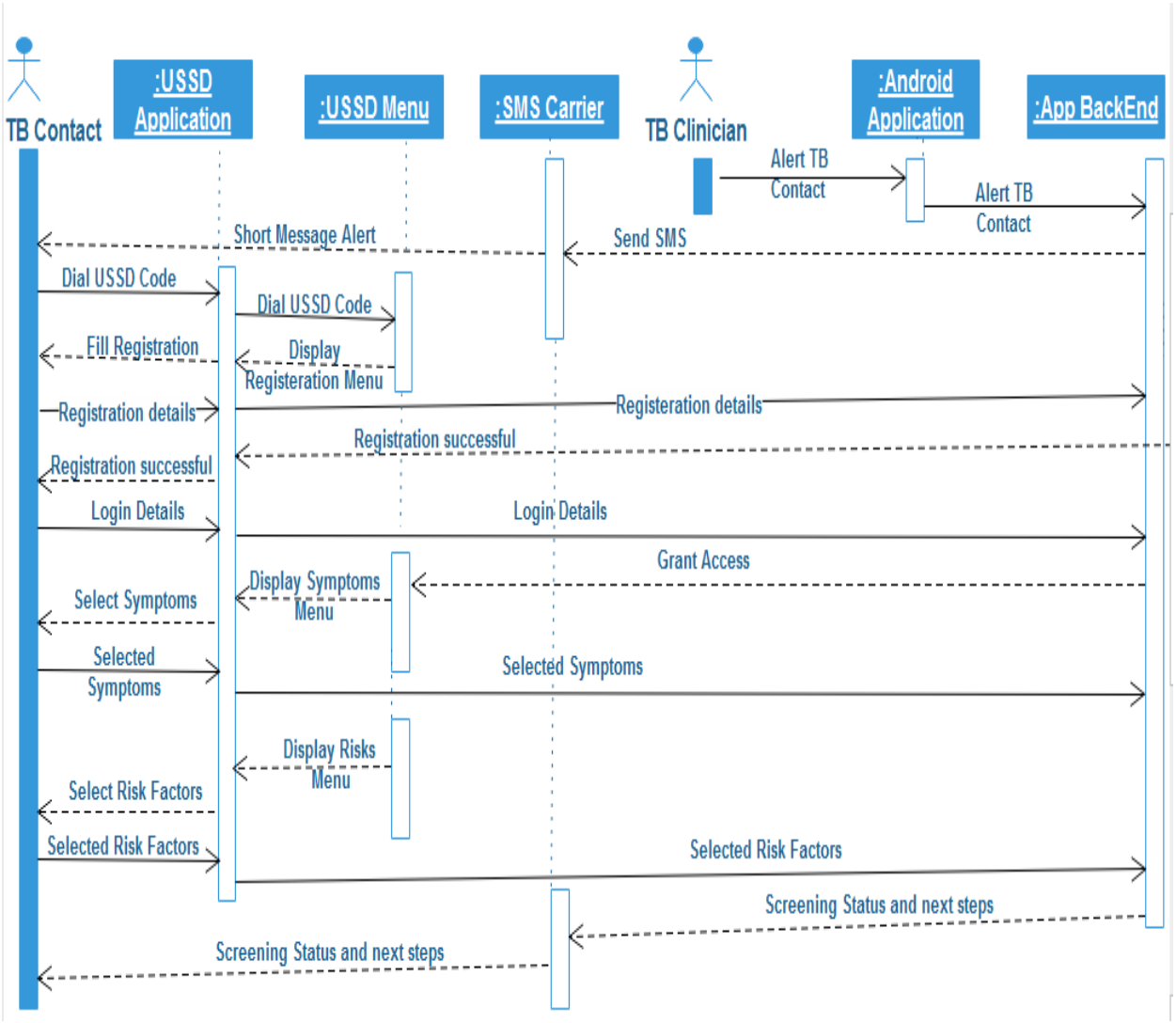

Figure 4. 7 Sequence Diagram

4.4.3 Use Case Diagram

Figure 4.8 illustrates the use case diagram. This comprises of five main primary actors which include the TB patient, TB contact, TB clinician, Administrator, and TB policy officials. The use cases include; provide TB contacts, add a TB contact, dial USSD code, register, select symptoms, select risk factors, receive SMS , record TB laboratory test, add a new service, update a service,

delete a service, and view analytics. They include and extend relationships are also represented to show relationship between use cases. The SMS carrier is an external system, which send a short message to the TB contact. The use cases are further discussed in detail after the presentation of the diagram.

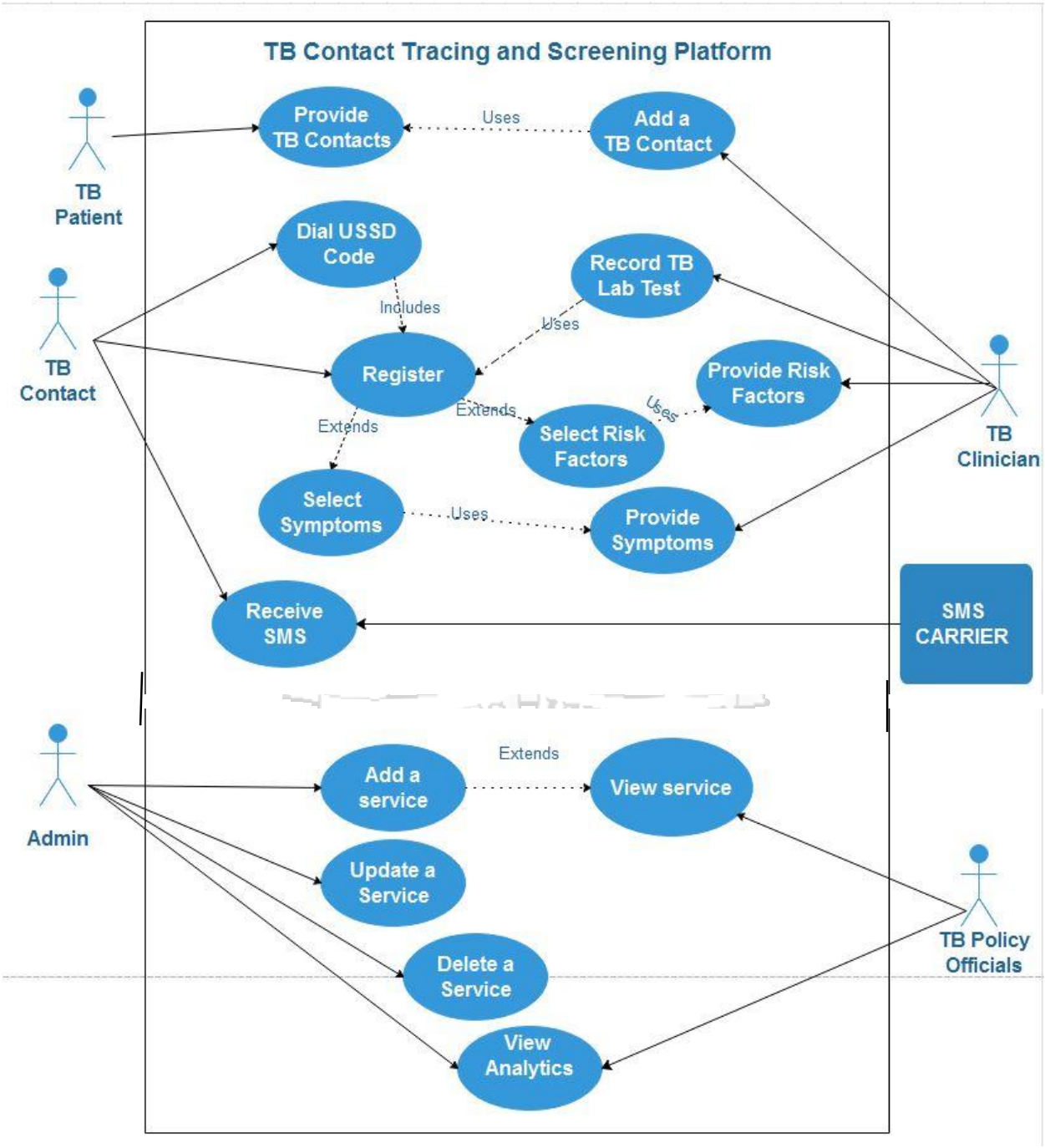

Figure 4. 8 Use Case Diagram

Use Case Description

Discussed below are the use case descriptions for the major use cases

Table 4. 1 Add a TB Contact Use Case

Use Case 1: Add a TB Contact	
Use Case Description: This use case describes how a TB contact is identified and indexed	
Primary Actors: TB Patient and TB clinician	
Pre-conditions: A patient has been tested and confirmed to have TB The TB clinician is successfully logged into the Android Application	
Post-condition: TB contact identified, indexed and alerted.	
Main Success Scenario	
Actor	**System**
1. TB Patients lists down his contacts to the TB clinicians 2. TB clinicians inputs the data through an Android application	3. System captures the details of the contacts as inputted , stores them and alerts the contacts to dial a USSD code for purpose of screening

Table 4. 2 Dial USSD Code Use Case

Use Case 2: Dial USSD Code
Use Case Description: This use case describes how a TB contact use case describes how a TB contact views the menu
Primary Actors: TB Contact
Pre-conditions: TB Contact is issued with a USSD short code
Post-condition: The TB contact dials the USSD short code and is able to view the application menu
Main Success Scenario

Actor	**System**
TB contact dials USSD Code	Systems displays the Register/log in Menu
TB contact fills registration and Logs in	System displays the screening menu

Table 4. 3 Select Symptoms Use Case

Use Case 3: Select Symptoms	
Use Case Description: This use case describes how a TB contact selects his/her symptoms so that the system is able to capture them for screening	
Primary Actors: TB Contact	
Pre-conditions: TB Contact is logged into the application	
Post-condition: The TB contact symptoms are captured for the purposes of screening	
Main Success Scenario	
Actor	**System**
1. TB contact selects symptoms screening menu. 2. TB contact answers the symptoms questions by selecting yes or no.	3. Systems displays a set of symptoms questions. 4. System captures the responses and store them. 5. System instructs the TB contacts to continue to risk assessment.

Table 4. 4 Select Risk Factors Use Case

Use Case 4: Select Risk Factors
Use Case Description: This use case describes how a TB contact fills the risk factors of contracting TB and the system captures them for the purpose of triage
Primary Actors: TB Contact
Pre-conditions: TB Contact is logged into the application
Post-condition: The TB contact symptoms are captured for the purposes of triage

Main Success Scenario	
Actor	**System**
1. TB contact selects risk assessment menu. 2. TB contact answers the risk factors questions by selecting yes or no.	3. Systems displays a set of risk factors questions. 4. System captures the responses and store them. 5. System instructs the TB contacts to check his status notification

Table 4. 5 Receive SMS Use Case

Use Case 5: Receive SMS	
Use Case Description: This use case describes how a TB contact is able to receive advice after the triage of the symptoms and the risk factors	
Primary Actors: TB Contact	
Pre-conditions: TB Contact has completed selecting the symptoms and the risk factors	
Post-condition: The TB contact receives a SMS instructing the next actions he should take	
Main Success Scenario	
Actor	**System**
1. TB contact selects check status on the menu.	2. System sends a SMS with instructions to the TB contact

Table 4. 6 Record Laboratory Test Results Use Case

Use Case 6: Record Laboratory Test Results
Use Case Description: This use case describes how a TB clinicians records the laboratory tests of the TB contact
Primary Actors: TB Clinician

Pre-conditions: TB Contact has received a SMS requiring him/her to visit a TB clinic ,and the TB clinician has undertaken a laboratory test	
Post-condition: The TB clinician successfully updates the TB status of the TB patient indicating that the contact is positive or negative and they are stored in the database.	
Main Success Scenario	
Actor	**System**
1. The TB clinician logs into the android application. 3.The TB clinician selects Record lab results 5. The TB clinicians fills and submits the results of the contact	2. The application displays main menu 4.System displays contacts 6. Lab results of the TB contact are successfully submitted in the database

Table 4. 7 View Analytics Use Case

Use Case 7: View analytics	
Use Case Description: This uses describe how an admin or TB policy officials view the various analytics.	
Primary Actors: Administrator and TB policy officials	
Pre-conditions: Responses have been captured on the back end and stored	
Post-condition: The admin or TB policy officials are able to view analysed data.	
Main Success Scenario	
Actor	**System**
1. The admin/TB policy officials logs into the system	3. The system presents the dashboard. 4. System displays analysed data.

2. The admin/TB policy officials selects the reports they want displayed	

4.5 System Design

Object-oriented design (OOD) techniques were used to refine the object requirements definition identified during system analysis and to define design-specific objects. In order to meet the objectives, user requirements were merged with the researcher specifications to establish a system design that accomplished the functionalities desired.

4.5.1 Design Class Diagram

Figure 4.9 shows the interactions of all system classes, attributes, and corresponding methods

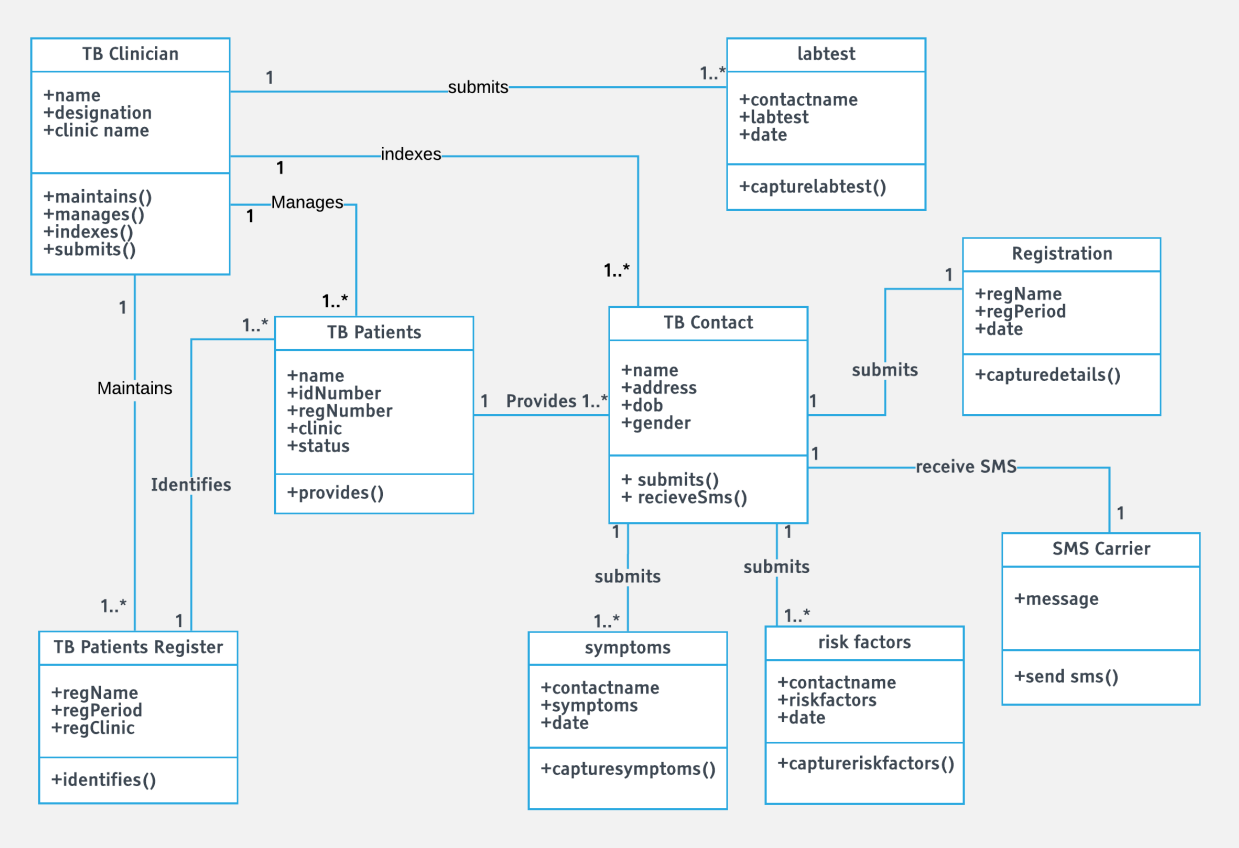

Figure 4. 9 Design Class Diagram

4.5.2 Entity Relationship Diagram

Figure 4.10 shows the entity relationship diagram that illustrates the conceptual view of the database as well as the relationship between tables.

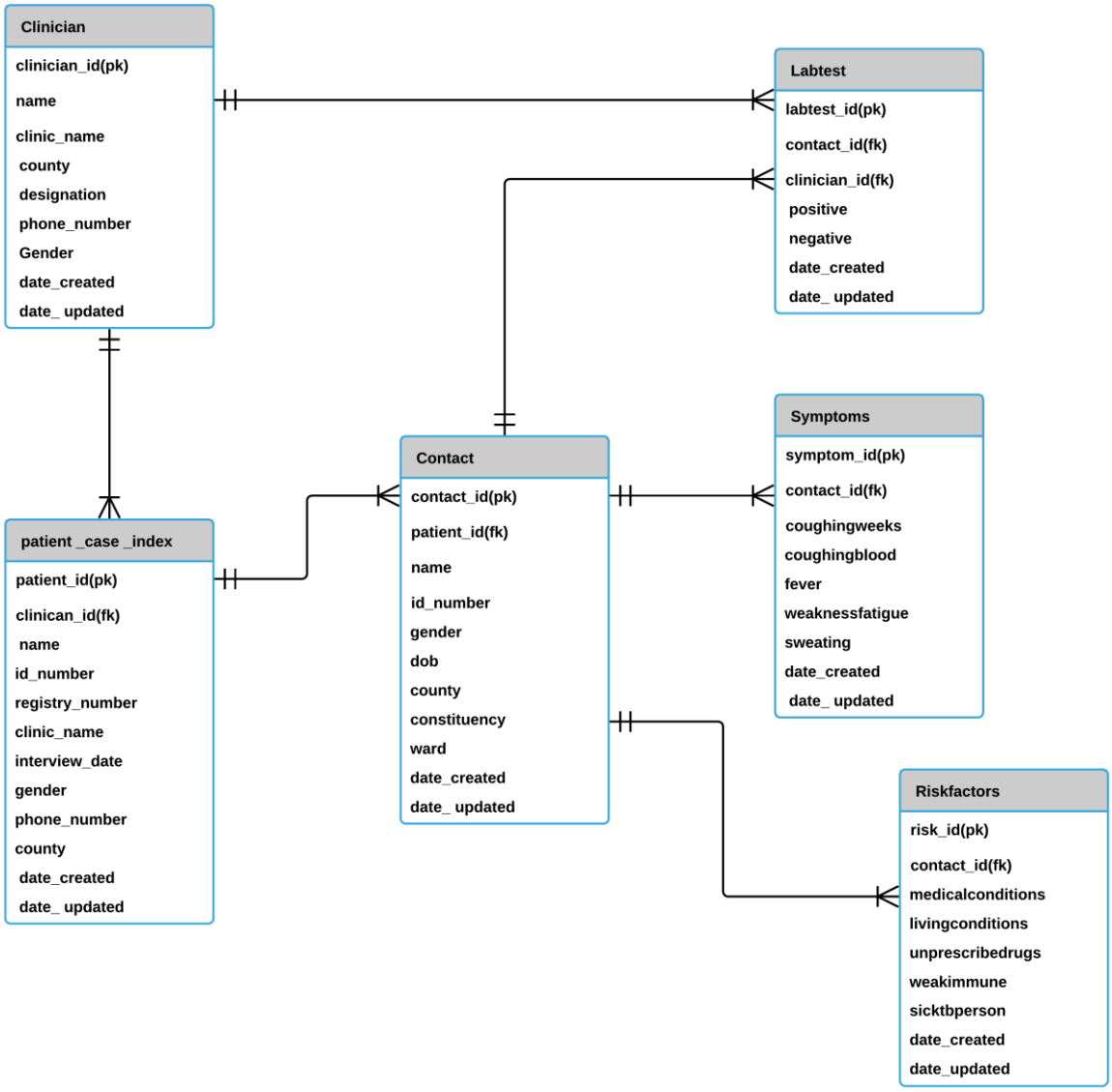

Figure 4. 10 Entity Relationship Diagram

Database Tables Overview

Table 4. 8 Database Tables Overview

Table Name	**Description**
Clinicians table	This table contains details of clinicians who index TB patients and record lab results of TB contacts
Patient Case Index table	This table contains details of confirmed TB patients who have listed their TB contacts
Contacts table	This table has details of the TB contacts
Symptoms table	This table holds details of symptoms of the TB contacts.
Risks table	This table hold details of risks associated in contracting TB of the TB contacts
LabTest table	This table has information of the lab test results of the contacts

4.5.3 Database Schema

The following tables shows the entities and the fields as well as their corresponding primary and foreign keys included in the database design.

Clinicians Table

Table 4.9 shows the clinicians table that includes the detailed information of clinicians involved in tuberculosis management services.

Table 4. 9 Clinicians Table

Column Name	**Data Type**	**Index**
Clinician-id	Big Integer	Primary key
Name	Varchar(191)	
Clinic Name	Varchar (191)	
County	Varchar(191)	
Designation	Varchar(191)	
Phone number	Integer(15)	
Gender	Varchar(191)	
Date Created	DateTime	
Date Updated	Date Time	

Patients Case Index Table

Table 4.10 shows the Patient Index Case Table that includes the detailed information of confirmed TB patients.

Table 4. 10 Patients Index Case Table

Column Name	**Data Type**	**Index**
Patient-id	Big Integer	Primary key
Clinician-id	Big Integer	Foreign key
Name	Varchar(191)	
ID Number	Integer (10)	
Registry Number	Varchar(191)	
Clinic Name	Varchar(191)	

Interview Date	Varchar(191)	
Gender	Varchar(191)	
Phone number	Integer(15)	
County	Varchar(191)	
Date Created	DateTime	
Date Updated	Date Time	

Contacts Table

Table 4.11 shows the contacts Table that includes the detailed information of all TB contacts

Table 4. 11 Contacts Table

Column Name	**Data Type**	**Index**
Contact-id	Big Integer	Primary key
Patient-id	Big Integer	Foreign key
Name	Varchar(191)	
ID Number	Integer(10)	
Gender	Varchar(191)	
Date of Birth	Varchar(191)	
County	Varchar(191)	
Constituency	Varchar(191)	
Ward	Varchar(191)	
Date Created	DateTime	
Date Update	Date Time	

Symptoms Table

Table 4.12 shows the symptoms Table that includes symptoms of all the TB contacts screened.

Table 4. 12 Symptoms Table

Column Name	**Data Type**	**Index**
symptom-id	Big Integer	Primary key
Contact-id	Big Integer	Foreign Key
Coughing weeks	Integer(1)	
Coughing blood	Integer(1)	
Weight loss	Integer(1)	
Fever	Integer(1)	
Sweating	Integer(1)	
Fatigue	Integer(1)	
Date Created	DateTime	
Date Updated	Date Time	

Risk Factors Table

Table 4.13 shows the risk factors table that includes the risk factors of all the TB contacts.

Table 4. 13 Risk Factors Table

Column Name	**Data Type**	**Index**
Risk-id	Big Integer	Primary key
Contact-id	Big Integer	Foreign key
Sick TB person	Integer(1)	

Living conditions	Integer(1)	
Weak immune	Integer(1)	
Unprescribed drugs	Integer(1)	
Medical conditions	Integer(1)	
Date Created	DateTime	
Date Updated	Date Time	

LabTest Table

Table 4.14 shows the LabTest Table that includes the results of all the TB contacts who have undergone a lab test.

Table 4. 14 LabTest Table

Column Name	**Data Type**	**Index**
LabTest-id	Big Integer	Primary key
Contact-id	Big Integer	Foreign Key
Positive	Integer(1)	
Negative	Integer(1)	
Date Created	Date Time	
Date Updated	DateTime	

4.6 Security Design

Security design consideration are based on a systems approach and data approach. The data approach security design was set to ensure confidentiality of the sensitive data such as the password for the administrator login. This design ensured that the password was hashed and would be maintained in this irreversible hash even in the storage. The system approach for security design entailed authenticate of access to ensure security of the system and data. The USSD application

required that contacts had login details before they could access the menu, the Android application ensured that only clinicians who had login details were able to access the application. The back-end web application authenticated all its users to ensure authorized access to modules.

4.7 Application Wireframes

The user interface was modelled using wireframes. USSD application, Android application and the web dashboard wireframes were modelled using balsamic software. Figure 4.11 shows the main menu of the USSD application. This includes symptoms screening, risk factors and check notification status. This are further represented in appendix D.

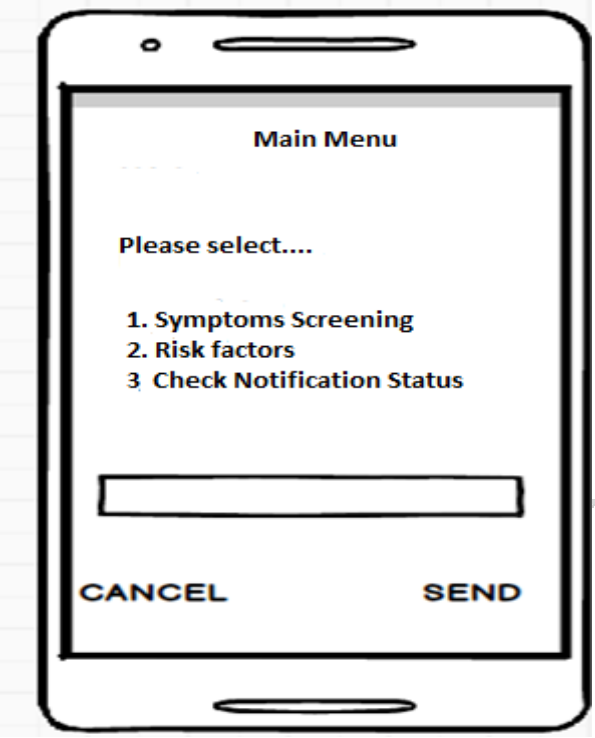

Figure 4. 11 USSD Main Menu

Figure 4.12 illustrates the main menu of the Android application. This shows the wireframes of the core functions of the android application. The individual wireframes are further represented in appendix D.

Figure 4. 12 Android Application Main Menu Wireframe

Figure 4.13 illustrates the dashboard of the web application. The web dashboard allows the user to navigate the user to view analysis of the data collected by the android and USSD application.

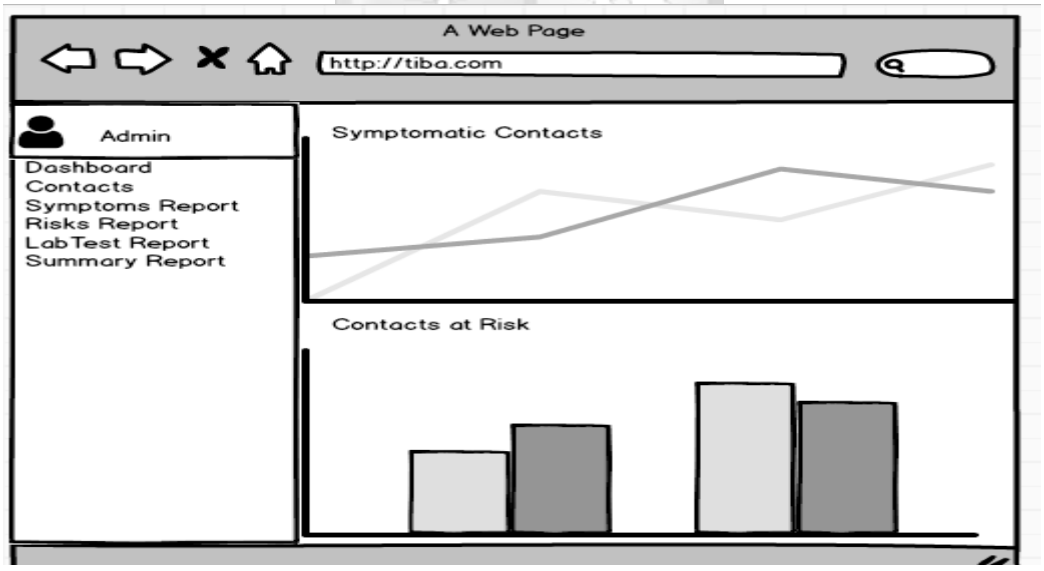

Figure 4. 13 Web Application Dashboard Wireframe.

Chapter 5: Prototype Building and Testing

5.1 Introduction

This chapter focuses on the implementation and testing details for both the mobile and the web solutions. The TB contacts interact with the system through the USSD based mobile application. The TB clinicians for the purposes of indexing the TB contacts and recording the lab results interacted with the system using an android application. The Web Application provides a portal where vital analytics for contact tracing and screening can be accessed along with also allowing the system administrator to manage the application. This chapter also includes the testing section, which includes functional testing and usability testing in order to establish if the system met the objectives of the proposed solution.

5.2 Implementation Environment

The system comprises of front-end and back-end subsystems: a front-end USSD application, a front-end mobile application and a web application, which is the back-end subsystem. Hypertext Preprocessor (PHP) programming language was used in implementing the USSD application. To send SMS confirmation messages a SMS gateway was employed. Android platform was used to develop the TB clinician's mobile application while the web dashboard was developed on Laravel 5.2, which is a PHP framework and was hosted using online apache HTTP server. PHP; Laravel was picked since it is open source and has a large community of online developers, implements the HTTPS protocol that prevents online attacks. PHP is also platform independent and compatible with all major web servers and databases. The database runs on MySQL since it is compatible with PHP and it is open source.

5.3 System Implementation

The system was implemented using a USSD application, Android application and a web backend known. The website backend enabled the administrator to manage the application and view reports, which is useful for data analytics.

5.3.1 Proposed USSD Application

The USSD application allows TB contacts to select their symptoms and risks for TB and triage them so to advice the patients what actions to take. To access this service, the user enters a short

code or text stings (e.g. *123#) which triggers the contact tracing and screening service in a session based communication. New users must register to access this service. Once a Registered user has dialed the short code, a menu appears which asks the user to login, the user logs in using his/her ID Number and Pin identification. The application then presents menus of symptoms screening. The user is able to answer the YES/NO questions in this menu and submits his or her responses to the application back-end. After completing the symptoms screening, the application then asks the TB contact to select the risk assessment menus. The user then answers the questions and submits responses to the application back-end. The user then selects check status so that he can receive further advice. Based on the symptoms and risk responses provided by the user, the application back-end is able to triage them and send an SMS to the user instructing the TB contact what actions to take. Figure 5.1 shows screenshots of the main menus.

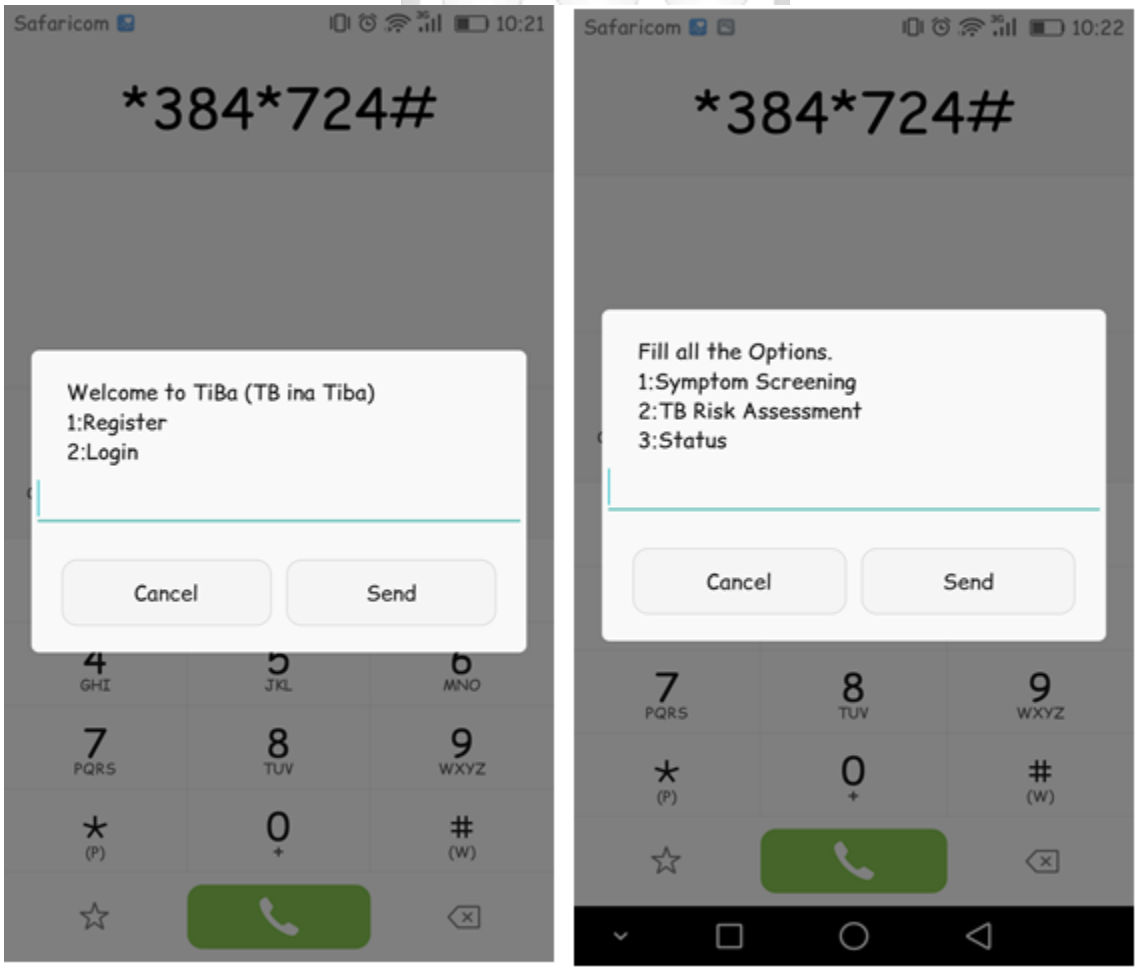

Figure 5. 1 Screenshots of Main Menus of the USSD Application

Figure 5.2 and 5.3 shows how a TB contact is able to select his/her symptoms and risk factors. The user selects the symptoms and the risk factors by inputting 1 or 2.

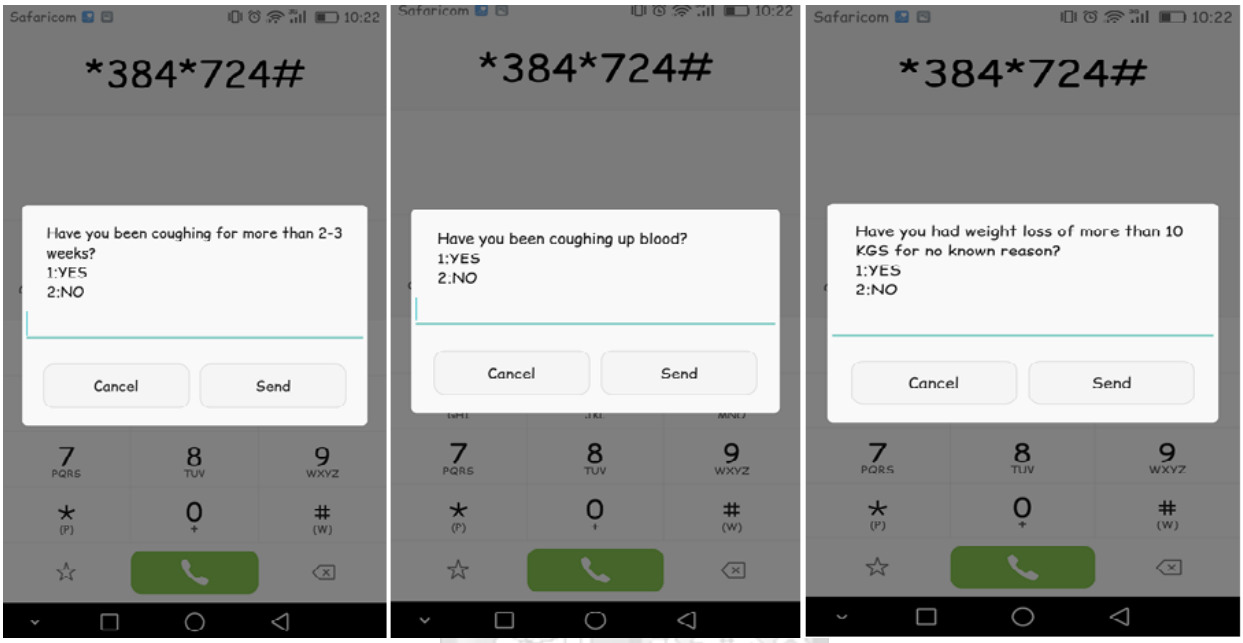

Figure 5. 2 Sample Screenshots of Symptoms Selection

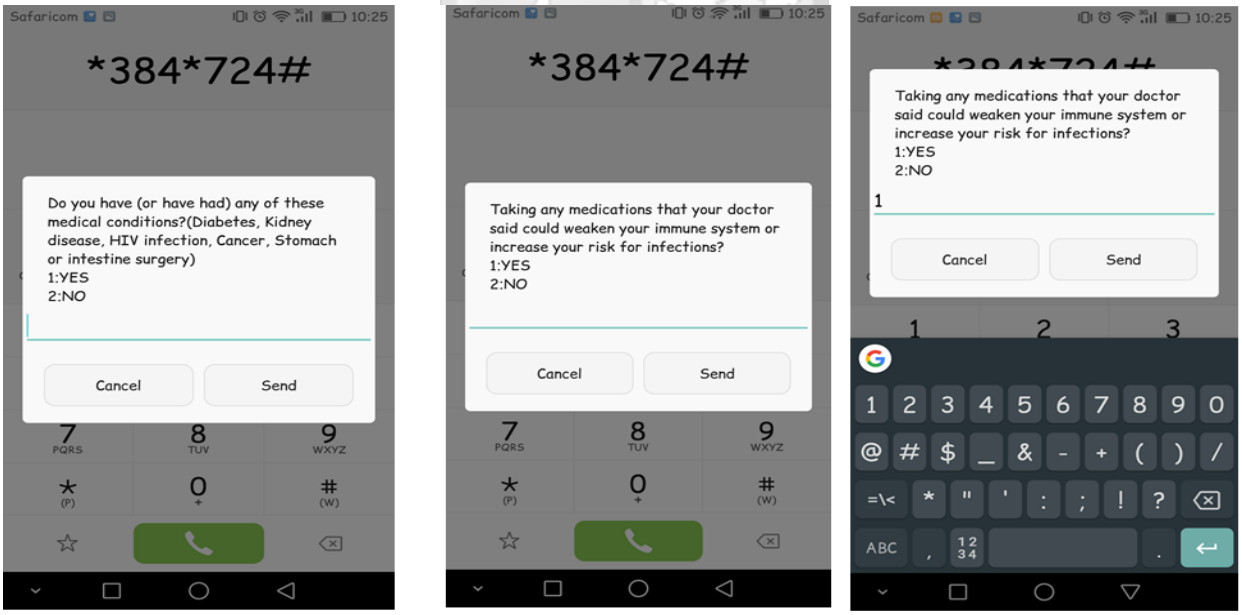

Figure 5. 3 Sample Screenshots of Risk Factors Selection

Figure 5.4 shows how a TB contact is able to check his status notification after selecting symptoms and risk factors

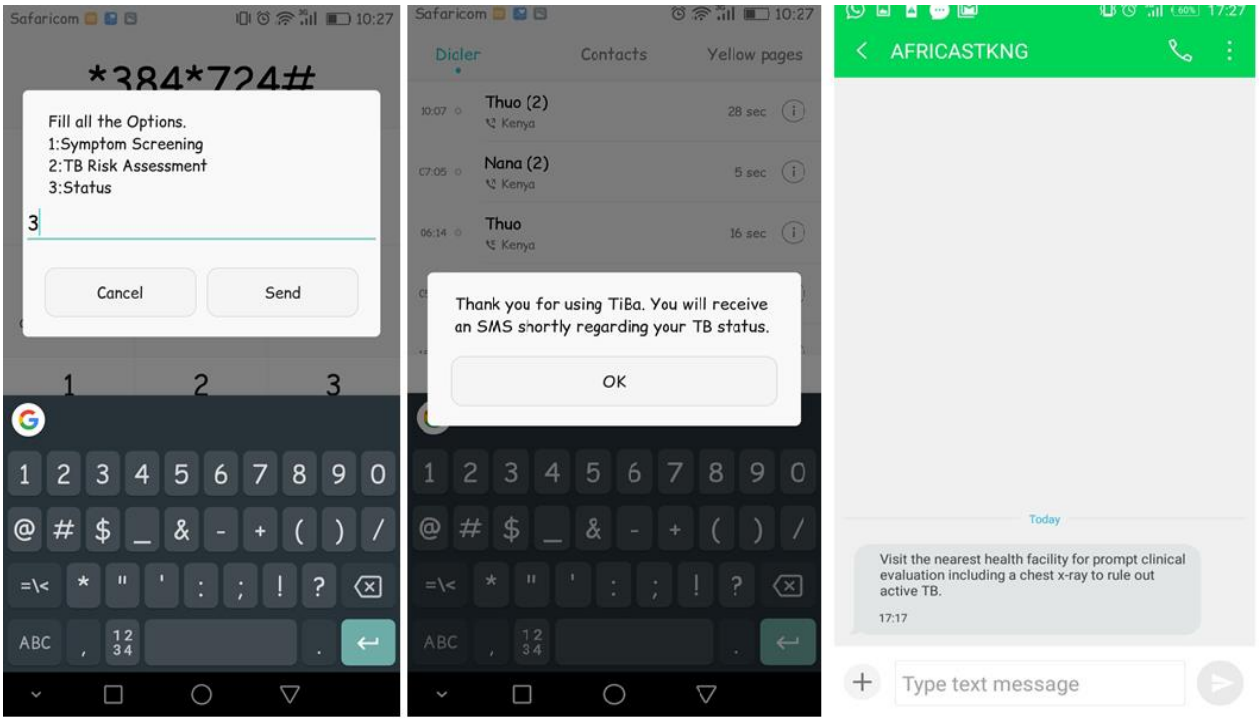

Figure 5. 4 Screenshots of Checking Status Notification

5.3.2 Proposed Android Application

The Android application allows TB clinicians to index TB cases and record the laboratory results of TB contacts. To access the application TB clinicians must register and then login. The Android application will then display a menu of TB case Indexing and recording Lab results. TB case indexing allows a TB clinician to record details of the TB patient and more important the TB contacts of this TB patients. This helps in identifying the TB contacts. Important details of TB contacts captured include their names and mobile numbers. The Android application communicates with the application back end so that it can send SMS to the TB contacts identified using this mobile number. The Android application also allows the TB clinicians to record the laboratory results of the TB contacts. This is involves pulling data of the TB contacts from the database and updating whether their laboratory results indicate if they are positive or negative. These results are submitted to the application server for reporting purposes. Figure 5.2 is a

screenshot of how Clinicians capture the details of a TB patient and add the contacts related to this TB patient.

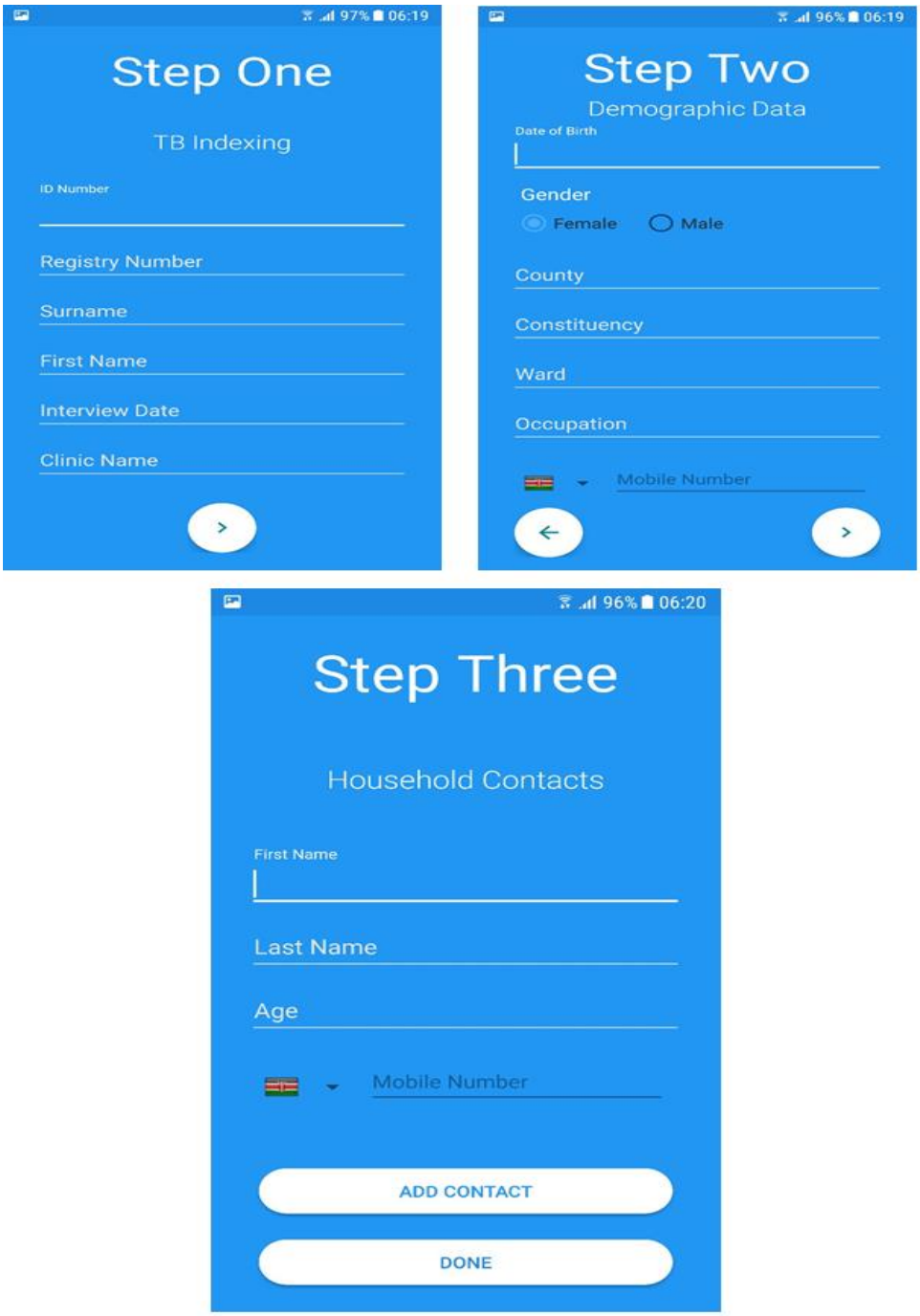

Figure 5. 5 Screenshot of TB Patient Indexing

5.3.3 The Web-Application

The Web-application complements the USSD and Android application in various ways. To access the Web application a user must have login credentials. The Web application presents the symptoms report, risks report and the laboratory test reports of the TB Contacts. This analytics can help in decision making for TB policy officials in their TB management activities. Figure 5.6 shows the main dashboard. This shows the various reports and refined analysis of data.

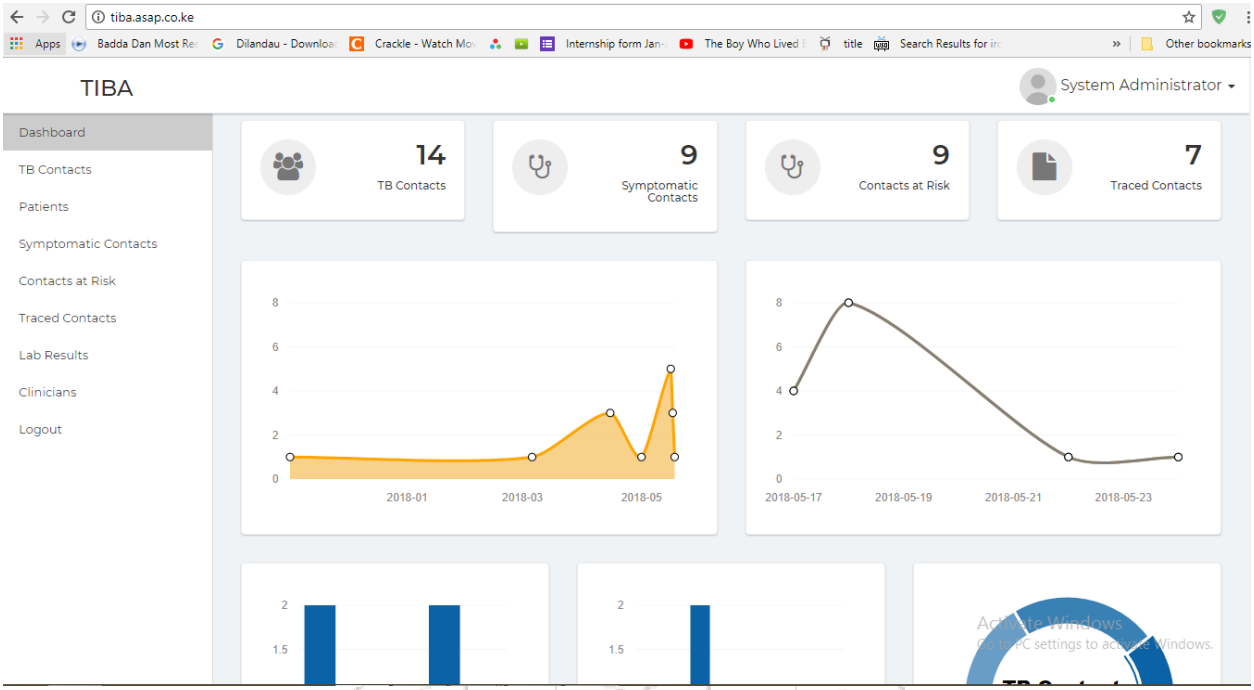

Figure 5. 6 Screenshot of Web Application Dashboard

5.4 System Testing

The system testing section discusses the various tests carried on both the mobile and web application. Agile testing was used in the research, which involved testing software for bugs or performance issues within the context of an agile workflow. Testing is usually a quality gate and the QA test group often serves as the quality gatekeeper. Agile testing enables building the product well from the beginning using testing to provide feedback on an ongoing basis about how well the emerging product is meeting the business needs (Hendrickson, 2008). Agile testing was applied continuously during the software development to ensure that the features implemented during a given iteration are actually done. Testing was done on three main areas; functionality tests, usability tests and compatibility tests.

5.4.1 Functional Testing

Functional tests were carried to determine whether the system design and its implementation was a success or a failure. Test cases were derived to comprehensively test key mobile and web application components. The test results were evaluated based on Item Pass/Fail Criteria.

Test Identifier 1: USSD Login

Table 5.1 shows results of test identifier one whose main assessment was to check if the user was able to Login using correct credentials. The observed and expected behavior were consistent. Test Identifier one passed the trial and outcome was deemed successful

Table 5. 1 USSD Login Test Case

Utilized Use Case	USSD Login
Test Parameters	User logs in with correct credentials
Expected Behaviour	Successful Login
Observed Behaviour	Successful Login
Test Outcome	Pass

Test Identifier 2: To Select Symptoms

Table 5.2 shows results of test identifier two whose main assessment was to check if the TB contact was able to select his /her symptoms. The observed and expected behavior were consistent. Test Identifier two passed the trial and outcome was deemed successful.

Table 5. 2 Select Symptoms Test Case

Utilized Use Case	Select Symptoms
Test Parameters	Successful selection of symptoms
Expected Behaviour	User symptoms are selected successfully

Observed Behaviour	User symptoms were selected successfully
Test Outcome	Pass

Test Identifier 3: To Select Risk Factors

Table 5.3 shows results of test identifier three whose main assessment was to check if the TB contact was able to select his/her risk factors. The observed and expected behavior were consistent. Test Identifier three passed the trial and outcome was deemed successful.

Table 5. 3 Select Risk Factors Test Case

Utilized Use Case	Select Risk Factors
Test Parameters	Successful selection of risk factors
Expected Behaviour	User risk factors are selected successfully
Observed Behaviour	User risk factors were selected successfully
Test Outcome	Pass

Test Identifier 4: Receive Correct SMS

Table 5.4 shows results of test identifier one whose main assessment was to check if the TB contacts received the correct SMS based on the combination of the responses of symptoms and risk factors. The observed and expected behaviour were consistent. Test Identifier four passed the trial and outcome was deemed successful.

Table 5. 4 Receive Correct SMS

Utilized Use Cases	Receive SMS
Test Parameters	Correctness of SMS received by TB Contact
Expected Behaviour	TB contact receives correct SMS
Observed Behaviour	TB contact received the correct SMS
Test Outcome	Pass

Test Identifier 5: Add a TB contact

Table 5.5 shows results of test identifier one whose main assessment was to check if the TB clinicians were able to add a TB Contact in the android application. The observed and expected behavior were consistent. Test Identifier five passed the trial and outcome was deemed successful.

Table 5. 5 Add a TB contact

Utilized Use Cases	Add a TB Contact
Test Parameters	Successful indexing of TB Contacts
Expected Behaviour	TB contact details are successfully added
Observed Behaviour	TB contact details were successfully added
Test Outcome	Pass

Test Identifier 6: Record TB Lab Test Results

Table 5.6 shows results of test identifier one whose main assessment was to check if the TB clinicians were able to record the successfully the laboratory results of the TB Contacts. The

observed and expected behavior were consistent. Test Identifier six passed the trial and outcome was deemed successful.

Table 5. 6 Record TB Lab Test Results

Utilized Use Cases	Record TB Lab Test Results
Test Parameters	Successful capturing of the Lab Test results of the TB Contacts
Expected Behaviour	TB Lab Test recording is successful
Observed Behaviour	TB Lab Test recording was successful
Test Outcome	Pass

5.4.2 Usability Testing

Both Mobile and Web Applications were tested for user friendliness. This was tested by confirming that both applications satisfied the user requirements as per what the user expected. USSD based Mobile applications are session based. A user friendly USSD based mobile application allows user to complete a transaction to safe state before session times out. Therefore, the usability tests for the mobile solution were designed to evaluate the aforementioned feature. The USSD application is limited by session time. The time taken by an average user when raising alert plus the minimum USSD session length was considered to effectively derive usability level of the USSD application. For the Android application and the Web Application, the systems cosmetic features, navigation and its ease of use were tested. The color and font properties were checked to ensure that they are auspicious to the user. A total of 30 respondents carried out the user testing practice giving appropriate feedback for the research. 30 respondents were used, as these were the only individuals who created time to be a part of the testing exercise. User testing was done to achieve the following objectives:

i. User friendliness

ii. functionality

iii. Aesthetics

iv. Acceptance

This section will focus on each of the mentioned objectives in detail. The findings will be presented graphically for an elaborative visual presentation.

i. User Friendliness

Potential users tested the ease of learning and using the application. 98% of the targeted users agreed that the developed application was easy to use and learn. Figure 5.7 illustrates these results.

Figure 5. 7 User Friendliness Testing

ii. Functionality

Potential users of the mobile application and web application tested how the system functioned against the specifications that were provided. 95% of the potential users indicated that they were satisfied with functionality of the application. This meant that the developer was to achieve most of the requirements specification and user functionality. 5% of the potential users indicated to be not satisfied with the mobile and web application. This meant that the developer did not meet some user specifications. These findings were used to refine the system until it was acceptable. Figure 5.8 illustrates these results.

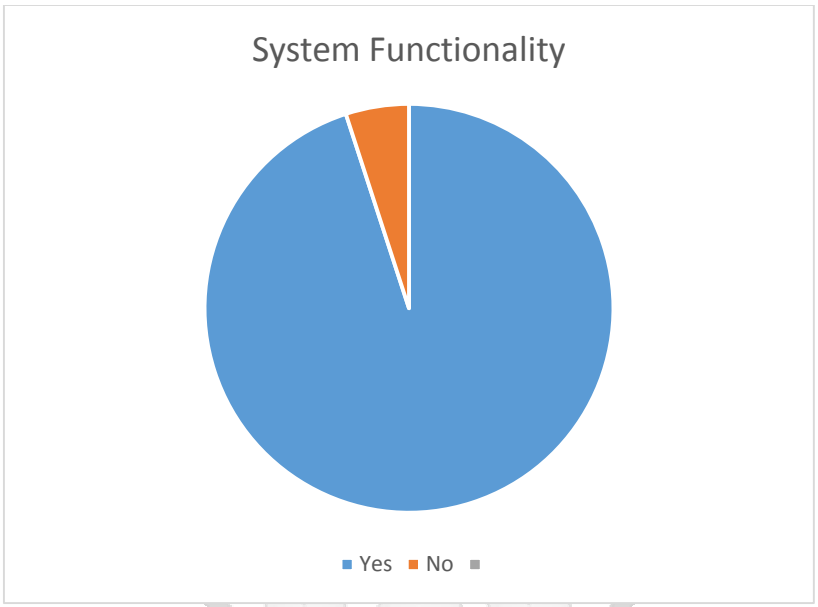

Figure 5. 8 System Functionality Acceptance Testing

iii) Acceptability

In order to establish if the system was a great success, user acceptance was conducted. 96% of the potential users indicated that they gladly accepted the system for use in the activities of TB contact tracing and screening. 4 % did not accept the application meaning that there were some aspects about the system they wished were different. Acceptance of the system was deemed a great success since majority of the target users gladly accepted it.

Figure 5. 9 Acceptability Testing

iv) Aesthetics

User interface aesthetics is defined by the look and feel of the application design and flow to its users. The Android application was tested for aesthetics. 82% of the respondents indicated that the application had an attractive presentation. 10% of the potential users indicated that application was attractive while the remaining percentage indicated that the Android did not please their eyes. A summary of the results can be viewed in Figure 5.4.

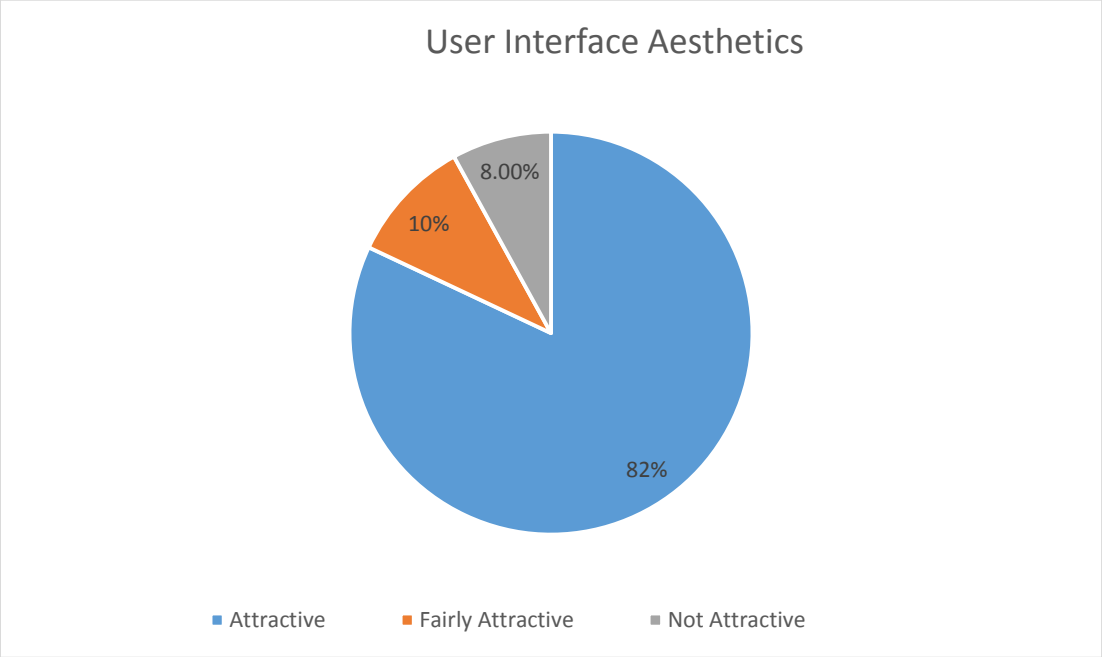

Figure 5. 10 User Interface Aesthetics

5.4.3 Compatibility Testing

Compatibility testing was carried out both on the Android and web application to ensure that they were compatible with existing platforms. The testing of the mobile application involved trying it on different Android versions while the testing of the web application involved trying it on all the major web browsers.

Android Platform Testing

Table 5.7 shows tests conducted on predefined and locally available Android platforms.

Table 5. 7 Test Done on Android Platforms

Android Platform	**Compatible**
Android 10 – 2.3.3	Yes
Android 11 – 3.0	Yes
Android 12 – 3.1	Yes
Android 13 – 3.2	Yes
Android 14 – 3.0	Yes
Android 15 – 4.0	Yes
Android 16 – 4.0.3	Yes
Android 17 – 4.1	Yes
Android 18 – 4.2	Yes
Android 19 – 4.3	Yes
Android 20 – 4.4	Yes
Android 21 – 4.4	Yes
Android 22 – 5.0	Yes

Web Browser Testing

Table 5.8 shows testing done on available and commonly used web browsers.

Table 5. 8 Test Done on Available Browsers

Web Browser	**Compatibility**
Internet Explorer – Version 4 and above	Yes
Mozilla Firefox – Version 4 and above	Yes
Chrome – all versions	Yes

5.5 System Evaluation and Validation

The evaluation and validation was done to ascertain whether the proposed system could be used in TB contact tracing and screening. The proposed system was passed under various test. With all the test cases done, it proved that the system in place was valid and beneficial to TB Management program. 15 potential users through an interview also supported this and the results were recorded.

Figure 5.11 shows what the users thought of the implementation and if the system solved the problem.

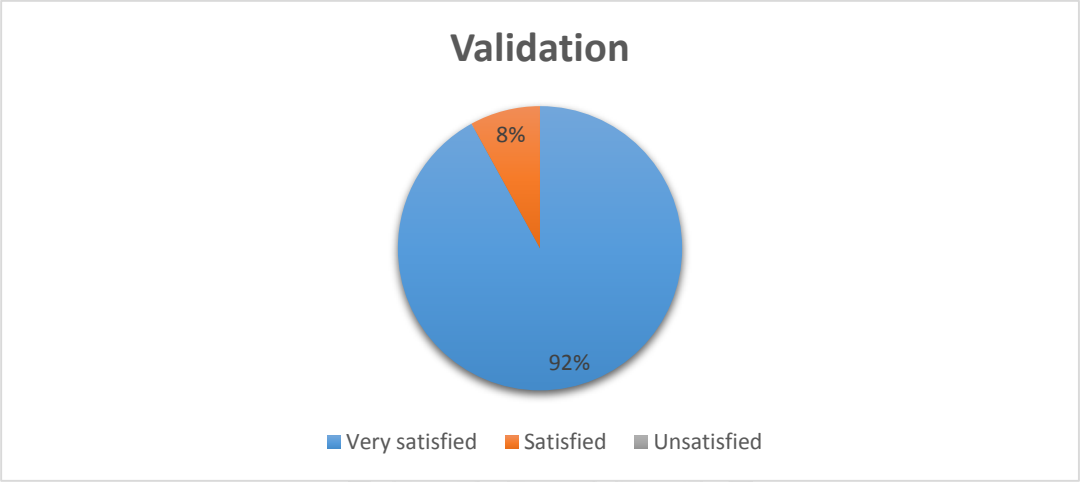

Figure 5. 11 Validation of System

5.6 Summary

TB contact tracing and screening encompasses a range of activities from identification of index patients, symptoms screening, risk assessment and laboratory tests. Relevant results are then presented to parties for action to be taken. The USSD application and Android application allows effective completion of this activities and data is saved in a secure database for further analysis. The web application module allows easier management of the application and also analyzing the data and displaying the results in charts, tables and graphical formats. In light of the application functional operation demonstrated above, the TB contact tracing and screening system whose key objectives are to improve surveillance and monitoring of TB patients and their contacts, complement the inadequate number of health workers involved in contact tracing and screening, reduce deficiencies in coordinating data collection and reporting is a reliable solution to the problem stated in the problem statement. The overall project adhered to a majority of the proposed objectives. The research was completed in ample time for testing and getting feedback from the application. System testing was done in three phases: Functionality Testing; was carried out to ascertain whether user requirements were met, User Testing was carried out to test for application functionality, user acceptance and user friendliness, Compatibility testing was carried out to ascertain whether the Android and web application were compatible with Android versions and web browsers respectively.

Chapter 6: Discussion

6.1 Introduction

The main purpose of this study was to develop a mobile-based application for TB contact tracing and screening. This involved specifically; analyzing the challenges of the existing TB contact tracing and screening models in Kenya, reviewing related architecture, models and application used in TB contact tracing and screening, developing, designing, testing and validating a mobile based application for TB contact tracing and screening. The findings obtained during the research formed the basis on which TB contact tracing and screening platform was developed. The application was tested to ascertain all its functionalities according to the research. This chapter analyzes the findings in relation to the research objectives and extent to what the findings agree with the literature review.

6.2 Review of Research Objectives in Relation to the Mobile Application

The research objectives of the study included; to analyze the challenges of the existing TB contact tracing and screening models in Kenya, to review related architecture, models and application used in TB contact tracing and screening, to develop, design and test a mobile based application for TB contact tracing and screening and lastly to validate the developed application.

6.2.1 Factors relating to TB Contact Tracing and Screening

The first objective sought to investigate the factors relating to TB contact tracing and screening activities. This involved understanding the process, the aims of the activity and the decision behind initiating contact tracing and screening activities. The literature revealed that the decision to initiate contact tracing for any individual TB case is based on the level of infectiousness of the index TB case and the characteristics of the contact. The literature review further revealed that, TB contact tracing serves several functions; identification of persons with Latent TB infection or TB disease among TB patients contacts, provision of adequate and prompt follow-up and treatment , reducing further transmission in household and places of work and lastly reducing morbidity and mortality of TB among person who have been newly infected.

6.2.2 Existing TB Contact Tracing and Screening Models

The second objective sought to review existing models, architecture and technologies used currently in TB contact tracing and screening. This information was useful to identify the strengths and limitations of each technique so that the researcher could choose the best technique to be adopted. To achieve this objective the researcher reviewed literature on current existing models, architectures and applications used in TB contact tracing and screening. The literature review revealed use of; paper forms, geographical information systems, mobile platform web platforms and a USSD platform. Mobile based techniques emerged to be the best approach for TB contact tracing and screening.

The second objective further sort to identify the challenges TB program officers face while carrying out the activities of TB contact tracing and screening in Kenya. The literature review revealed that TB program officers face a number of challenges, which include low surveillance and monitoring of TB patients and their contacts, inadequate number of health workers to cover sparse geographical locations, and deficiencies in coordinating data collection and reporting. The developed system was able to address the challenges highlighted.

6.2.3 TB Contact Tracing and Screening System

The second objective of the study explored designing, developing and testing a mobile-based system for TB contact tracing and screening. This objective was achieved through the design, implementation and testing of the system. The system was developed using a USSD application developed using PHP, mobile application developed using Android technology and a web application developed using Laravel framework. After the development of the system, the following tests were carried out; Functional testing to ascertain whether user requirements were met, User Testing was carried out to test for application functionality, user acceptance and user friendliness, Compatibility testing was carried out to ascertain whether the Android and web application were compatible with Android versions and web browsers respectively.

6.2.4 Validation of the Developed Solution

The third objective was to validate whether the developed mobile-based system for TB contact tracing and screening solved the existing challenges using the current technology. This objective was achieved using a questionnaire and interviews. The respondents indicated that the system met

the needs of the users in terms of functionalities and addressing the challenges faced with current system. This objective was therefore met with adequate satisfaction.

6.3 Advantages of the Application as Compared to the Current System

One of the Key advantages of the developed system as compared to the current system of paper based contact tracing and screening is, it is able to effectively trace and screen symptoms of TB contacts in real time without requiring that the health workers physically visiting the TB contacts and ask them to fill evaluation forms. It also ensure timely data collection and reporting ensuring that deficiencies experienced with paper based methods of contact tracing and screening are eliminated. The system also effectively and timely carries out surveillance and monitoring of TB patients and their contacts by presenting analytics in a timely manner to relevant parties as opposed to the current system.

6.4 Limitation of the system

USSD has a limited data size it can sent; it cannot be used to send a message bigger than 160 bytes / 182 characters. It is difficult to access the application when out of network range or dead zone such as inside an elevator. Additionally, USSD sessions are short lived and do not allow long inputs. Finally, the TB clinician mobile application requires users to have access to a smartphone. This requirement locks out TB clinicians who do not have access to such devices.

Chapter 7: Conclusions and Recommendations

7.1 Conclusions

The main goal of the dissertation was to develop a mobile-based system that can be used for TB contact tracing and screening and hence address the needs of TB officers in improving TB contact tracing and screening. The National TB program in Kenya is challenged by a high burden of TB infections and disease. Contact tracing and screening approaches exist but these approaches are faced by significant challenges as discussed in this dissertation. The incidence of TB disease in Kenyan people will not decline in the absence of effective and organized contact tracing and screening. The mobile-based system comes in handy to positively impact TB control efforts specifically in TB contact tracing and screening in Kenya. Studied literature revealed that the current system used in Kenya for contact tracing and screening was paper based, although other countries have employed web-based systems, Android applications, USSD systems and geographical information systems.

The challenges of TB contact tracing and screening in Kenya were successfully investigated. It was noted that the current system is faced with challenges of low surveillance and monitoring of TB patients and their contacts, inadequate number of health workers to cover sparse geographical locations, and deficiencies in coordinating data collection and reporting. The assessment showed that the current system of contact tracing and screening is paper-based along with MS- office applications for recording data. The researcher also further studied the related architectures, designs and models of contact tracing and screening and the gaps identified to provide an optimal solution.

The proposed solution is a mobile-based contact tracing and screening system with a Web dashboard. Agile methodology was used to design, develop and test the application. The design of the system involved coming with UML diagrams such as Use-case diagrams, sequence diagrams, context diagrams and entity relationship diagrams. User testing and evaluation statistics indicated that the system fulfilled its functionalities and usability requirements. Based on questionnaire responses, the system is generally considered easy to understand and use. Thus, the research objectives of the study can be said to have been achieved since the system met the needs of the users and received a good reception from target users.

7.2 Recommendations

The recommendations, which can be made, are that the National TB program and the Government of Kenya should recognize and embrace novel technologies for TB contact tracing and screening. The National TB program can also consider supporting the development of dedicated teams or units that facilitate novel methods for TB contact tracing and screening to complement the work of field health worker/ epidemiologists. More work needs also to be done on the web dashboard in terms of integration with existing systems, which the policy makers use. This will help avail information to the policy makers as soonest as possible.

In order to successfully integrate these novel methodologies of TB contact tracing and screening, community involvement, ongoing support at every level and capacity building will be required. This will enable in breaking the cycle of transmission by priotizing TB contacts who should undergo treatment of Latent TB infection and also help in systematically collecting analyzing and interpreting the TB contact tracing and screening data in communities that bear a heavy TB burden. Ultimately, the measure of success will be a clear and sustained decline in TB incidence in Kenya.

7.3 Future works

The research findings for this dissertation are not final and hence there exists more room for improvement. Key areas of further research include; developing a TB contact tracing geographical information system, developing and validating a network-informed TB contact tracing and screening tool, integrating this developed system with the existing systems used in disease surveillance in our country, integrating the Android application with intelligent clinical machines that have abilities of TB chest X-ray and lastly exploring the extent of use of the TB contact tracing and screening data that will be collected using this system proposed.

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Appendices

Appendix A: System Requirements Document:

WHO forms for TB Contact Tracing and Screening

Form 1: Indexing Form

FORM 1. INDEX CASE INTERVIEW AND CHART REVIEW: HOUSEHOLD ROSTER AND CLINICAL DATA

TB index case

ID _____ Registry number (For example: 7101/K/11/201)

Surname _____

First name _____

Interview date __ __ / __ __ / __ __ __ __ (Date the index case is interviewed)
(D D / M M / Y Y Y Y)

Clinic name _____

District TB coordinator _____

TB contact investigator _____

Was the patient screened for TB in the household?* ☐ Yes
☐ No

Demographic information

Date of birth ___ ___ / ___ ___ / ___ ___ ___ ___ (Date patient was born; if unknown, estimate)
(D D / M M / Y Y Y Y)

Gender ☐ Male ☐ Female

Address
Ward _____
Street _____
House number _____
Ten cell leader _____
Telephone number _____

Occupation
☐ Teacher ☐ Health care worker
☐ Correctional employee ☐ Farmer
☐ Petty trader ☐ Other
☐ Not employed in past 24 months
☐ Other, specify _____

Household contacts

Please list the household contacts for this patient:

Name	Gender	Age

FORM 2: Adult Screening Form for Tuberculosis

Click to Save
Click to Print

Adult TB Risk Assessment and Screening Form
(For Patient Record)

Name: DOB: Date:

TB Risk Assessment	Yes	No
1) Were you born in Africa, Asia, Central America, South America, Mexico, Eastern Europe, Caribbean or the Middle East? In what country were you born?	☐	☐
2) In the past 5 years, have you lived or traveled in Africa, Asia, Central America, South America, Mexico, Eastern Europe, Caribbean or the Middle East for more than one month?	☐	☐
3) In the last 2 years, have you lived with or spent time with someone who has been sick with TB?	☐	☐
4) Do you have (or have you had) any of these medical conditions? Diabetes, Kidney disease, HIV infection, Colitis, Cancer, Stomach or intestine surgery, Rheumatoid arthritis	☐	☐
5) Are you taking any medications that your doctor said could weaken your immune system or increase your risk for infections?	☐	☐
6) In the past 1 year, have you injected drugs that your doctor did not prescribe?	☐	☐
7) Have you ever lived or worked in a prison, jail, homeless shelter or long-term care facility? (example: nursing home, substance abuse treatment, rehabilitation facility)	☐	☐

Symptom Screening – At this time, do you have any of these symptoms?	Yes	No
1) Coughing for more than 2-3 weeks?	☐	☐
2) Coughing up blood?	☐	☐
3) Weight loss of more than 10 pounds for no known reason?	☐	☐
4) Fever of 100°F (or 38°C) for over 2 weeks?	☐	☐
5) Unusual or heavy sweating at night?	☐	☐
6) Unusual weakness or extreme fatigue?	☐	☐

If you answer "yes" to any of the questions above, you may be at increased risk for TB infection. Please give this form to your medical provider.

Triage Plan	
☐	**Person has TB risk and has one or more TB symptoms:** Refer the person for **prompt clinical evaluation** including a chest x-ray to rule out active TB
☐	**Person has TB risk, no symptoms and has no history of previous positive TB test:** Test for TB infection or refer for testing and evaluation
☐	**Person has a history of previous positive TB test, but has no evidence of treatment:** Refer for TB evaluation and treatment

Appendix B: Respondents Questionnaire

Dear Respondent,

My name is Stanslaus Mwongela a postgraduate student from Strathmore University, Faculty of Information Technology, conducting a research entitled, Tuberculosis Contact Tracing and Screening Application, Case of Nairobi County, Kenya.

You have been chosen to form part of this study. I kindly request you to help me in filling the questionnaire below. The information requested is needed for academic purposes only and will be treated in strict confidence.

Kind Regards,

Stanslaus Wambua Mwongela.

* Required Fields

SECTION A: BACKGROUND INFORMATION

1. What is your gender? * Mark only one oval.

   - Male
   - Female

2. What is your age group? * Mark only one oval.

   - 13-17
   - 18-24
   - 25-34
   - 35-54
   - 55+

3. Are you currently in ownership of a mobile phone? * Mark only one oval.

- Yes
- No

If **yes,** what model of phone do you own?

- Feature Phone
- Smartphone
- Both

4. Do you have any computer literacy skills? * Mark only one oval

- Yes
- No

If **yes** kindly, list the computer skills you possess e.g. Microsoft Package Suite –Excel, Word:

……

……

SECTION B: Contact Tracing and Screening

5. How many contact tracing and screening activities have you been involved in? * Mark only one oval

- One
- Two
- Three
- More

If **more,** indicate an approximate number……

6. What contact tracing and screening systems have you used? *

- Paper based system
- Computer based system
- Mobile based system

7. How often do you use the above-ticked systems?

- ◯ Daily
- ◯ Weekly
- ◯ Monthly
- ◯ Never

8. Are the above ticked (in Q12) contact tracing and screening systems functional? * Mark only one oval

- ◯ Yes
- ◯ No
- ◯ I do not know

9. How reliable is the current contact tracing and screening system? * Mark only one oval

- ◯ Reliable
- ◯ Sufficiently reliable
- ◯ Very Reliable
- ◯ Not Reliable

10. What Limitations have you experienced with the current system? *

- ◯ Centralization of data
- ◯ Report creation
- ◯ Data analysis
- ◯ Data and record distribution.
- ◯ Other

If other please list them:

……

……

11. What needs do you intend to fulfill with a Tuberculosis Contact tracing and screening system?

- ◯ Identification of contacts with positive symptoms to begin their treatment early
- ◯ Reduction of further infections
- ◯ Plan TB control
- ◯ Notify TB cases early
- ◯ Adherence to TB control strategies

If other please list them:

……

……

……..

12. What recommendations / changes would you love to see implemented in the current system?

……

……

……

SECTION C: Data processing, analysis and reporting

13. Where do you store the data collected from subjects?

- ◯ TB Register / Paper Based data storage
- ◯ Computer/ Laptop
- ◯ Web Portal
- ◯ Mobile Application

14. What do you do with the collected data?

……

……

15. How and when do you collect the data?

……

……

16. When do you use it and when does the purpose for it end?

……

……

……

17. Is there a business need for the data? (Is the information necessary?)

- ◯ Yes
- ◯ No

If **No** explain why

……

……

18. Who has access to it and what do they do with it?

……

……

19. How long do you keep it?

……

……

20. What data analysis tools do you use to analyze data collected?

- ◯ Statistical paper based
- ◯ Computer aided
- ◯ All
- ◯ None

Any further comments, suggestions or recommendations.

……

……

……

.

-END-

Appendix C: Usability Testing and Validation Questionnaire

Section A: Usability Testing

A1. How do you find the user interface of the mobile application based on its look and feel? (Choose ONE)

- Attractive
- Average
- Not Attractive

A2. Rate the system based on whether the application was easy to learn and use as a first time user? (Choose ONE)

- Good
- Fair
- Bad

A3. Rate the system functionality based on whether it met the user requirements? (Choose ONE)

- Yes
- No

A4. Would you use the mobile-based system for your contact tracing and screening activities? (Choose ONE)

- Yes
- No

Section B: Validation Testing

B1. Do the functionalities provided by the system solve the challenges of the the existing model? (Choose ONE)*

- Yes
- No

B2. Are you satisfied with solution provided by the systems as far as TB contact tracing and screening is concerned? (Choose ONE)*

- Yes
- No

B3. Would you recommend other concerned parties to use the system? (Choose ONE)*

- Yes
- No

Appendix D: Wireframes

USSD Application Wire frames

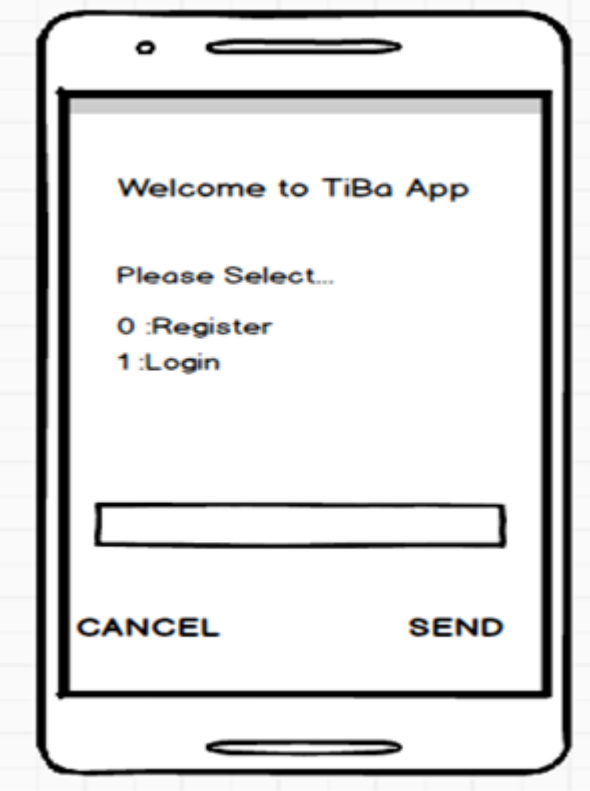


Figure D. 1 Welcome Page

Figure D. 2 Login Page

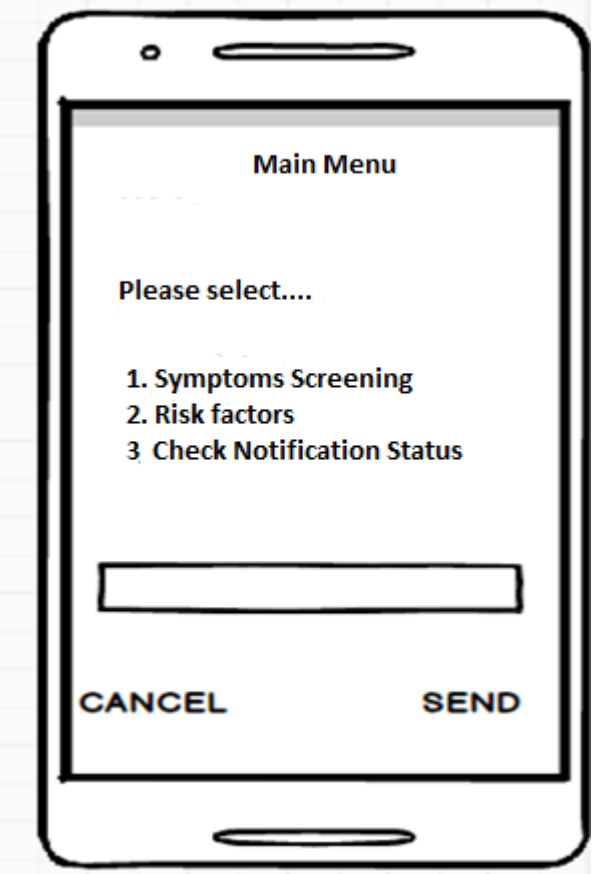
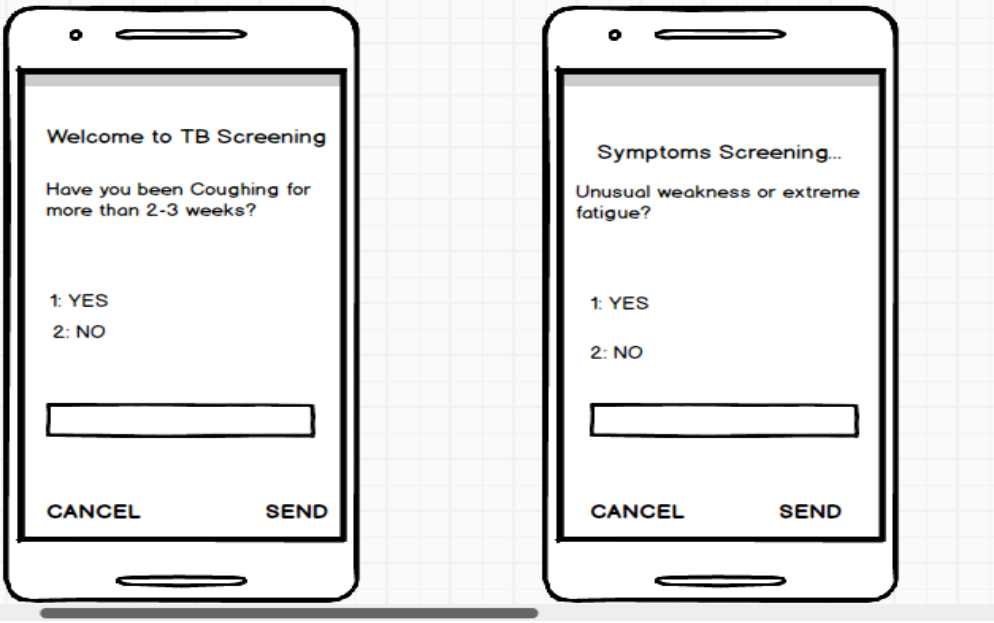


Figure D. 3 Main Menu Wireframes



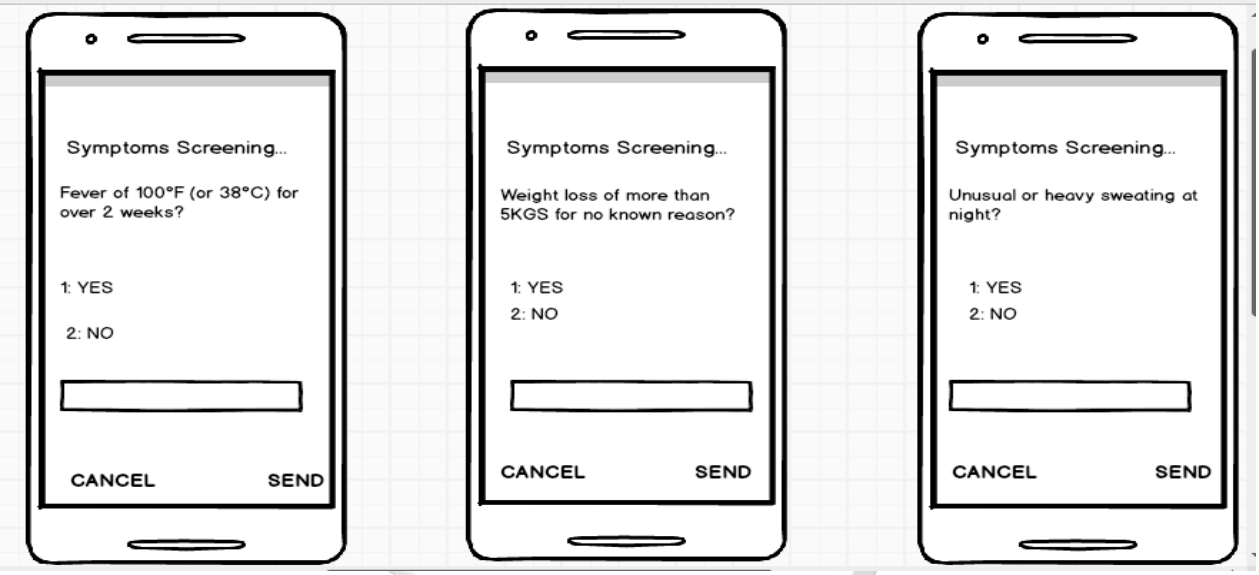
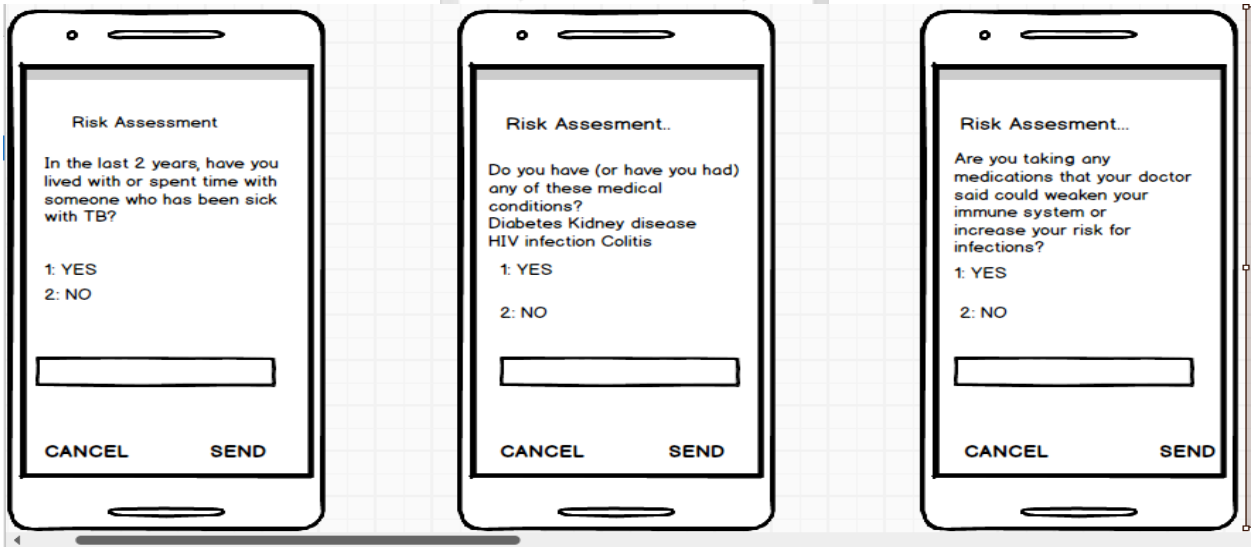


Figure D. 4 Symptoms Screening Wireframes



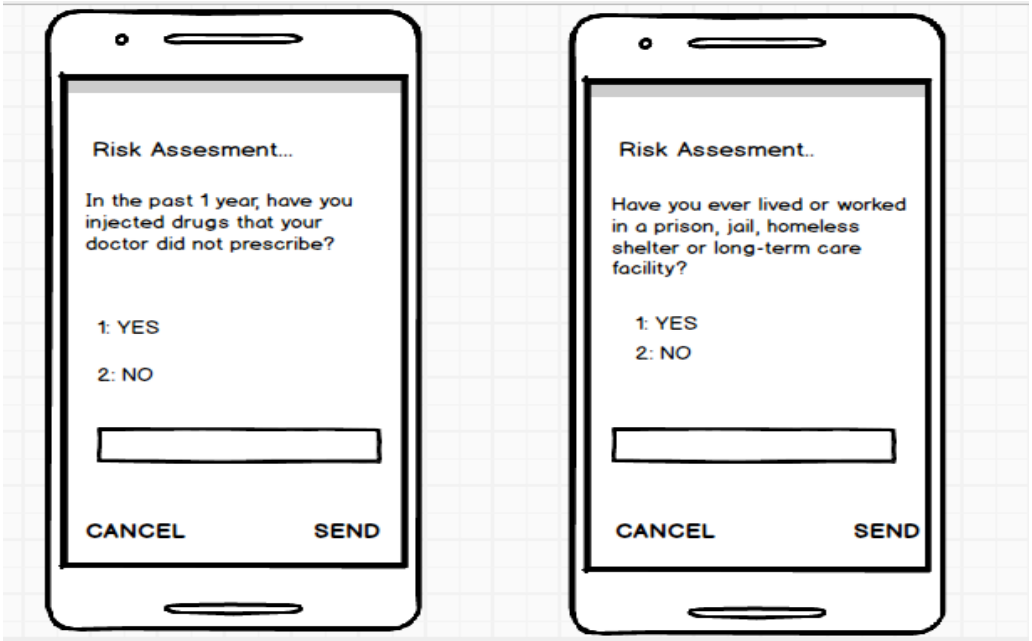
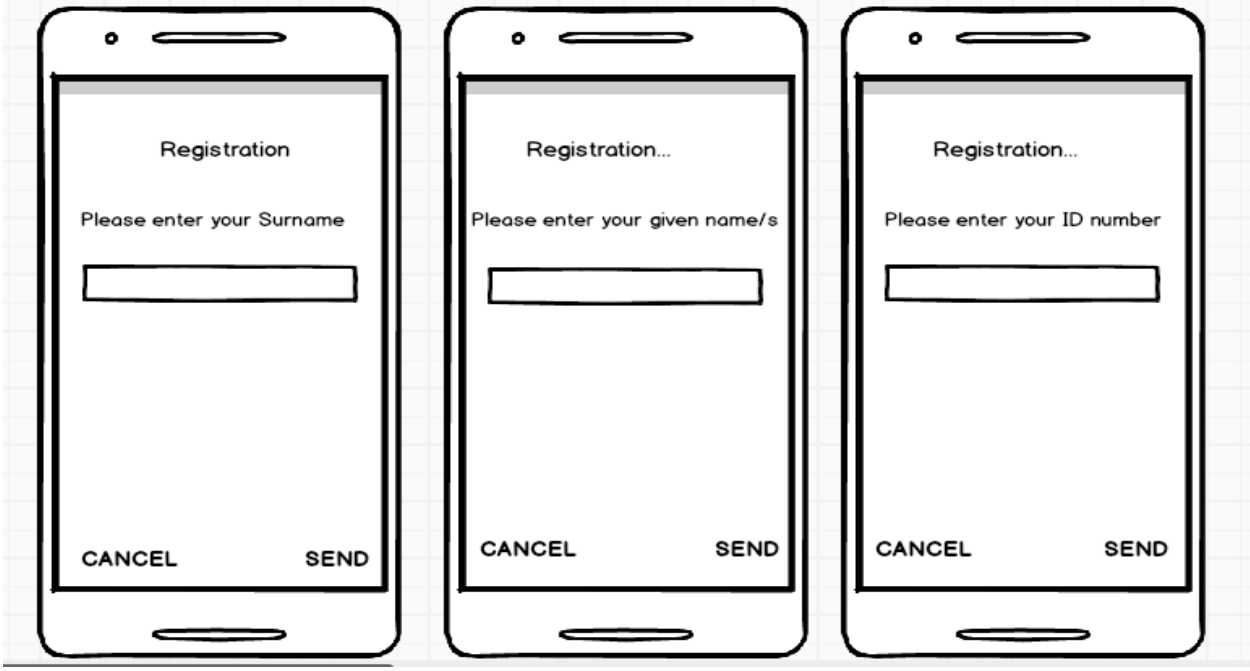


Figure D. 5 Risk Factors Wire Frame



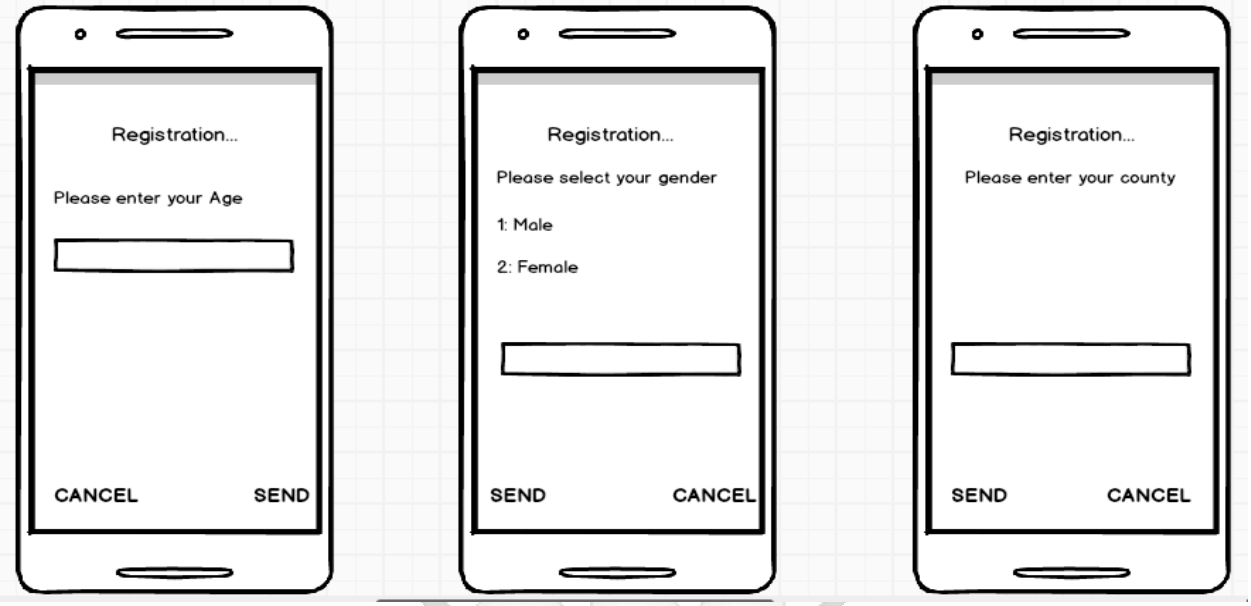


Figure D. 6 Registration Wireframes

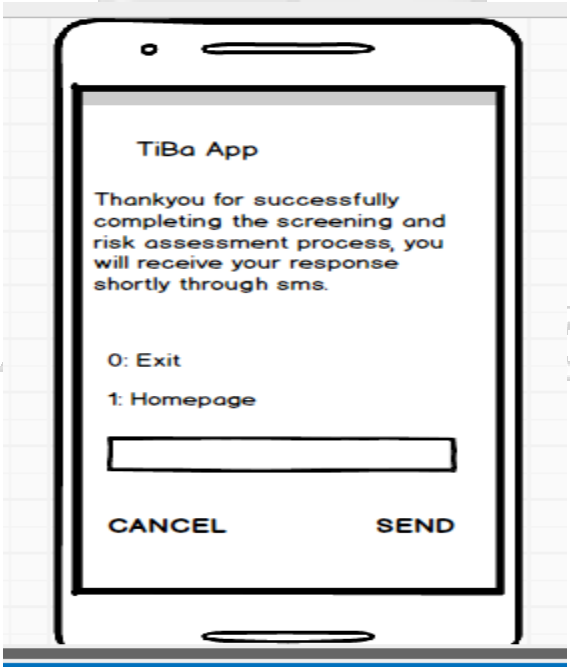


Figure D. 7 Notification Status Wireframe

Android Application Wireframes

Figure D. 8 Login Wireframe

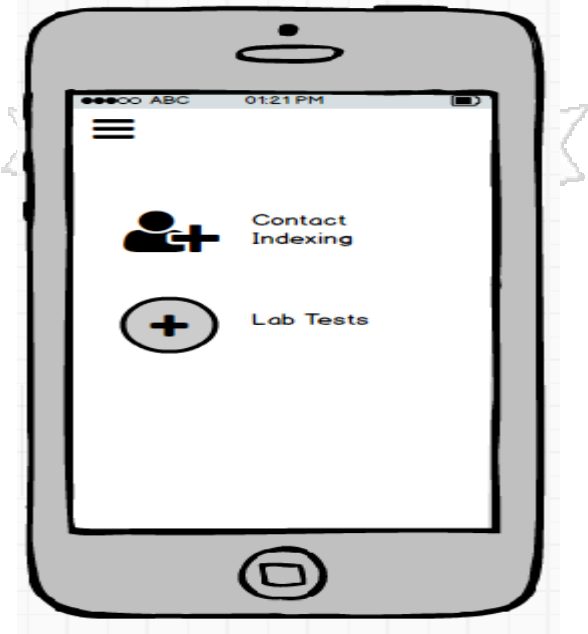


Figure D. 9 Main Menu Wireframe

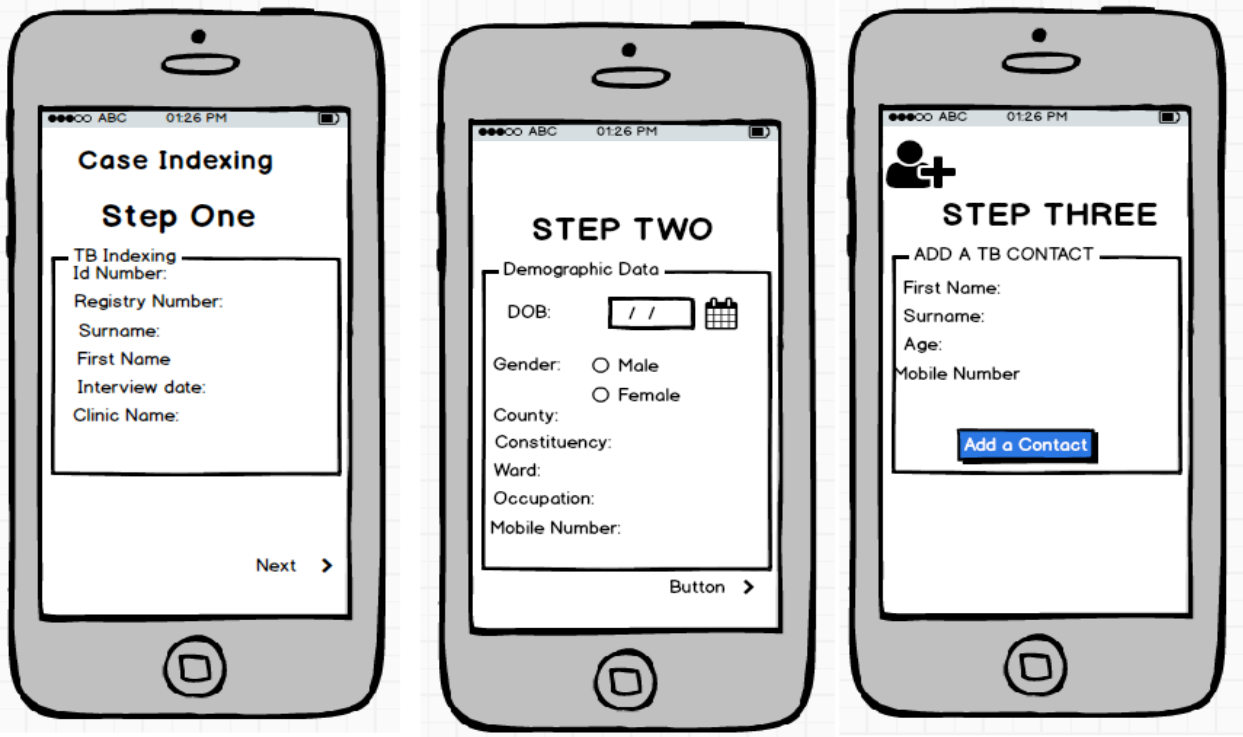


Figure D. 10 Case Indexing and Adding TB Contact Wireframe

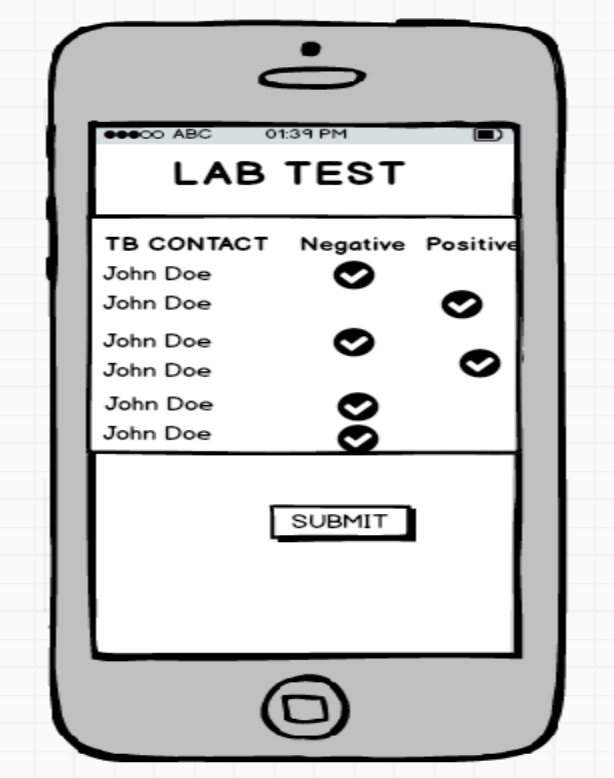


Figure D. 11 Labtest Recording Wireframe

Web Application Wireframes

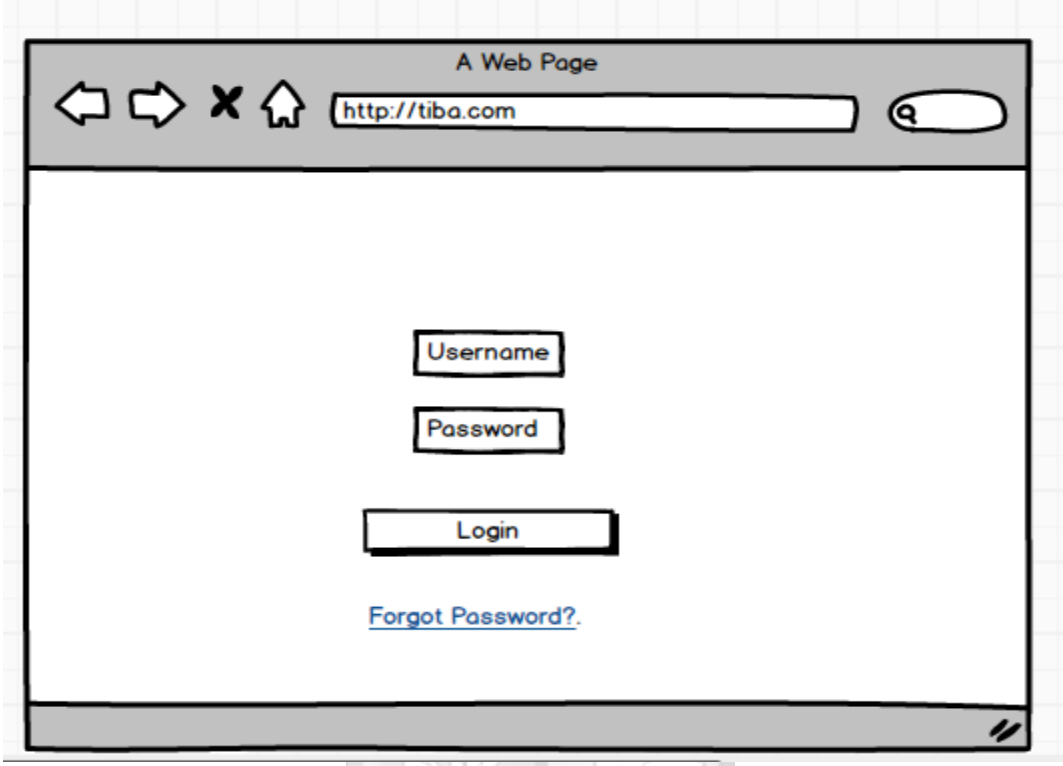


Figure D. 12 Web Application Login Wireframe

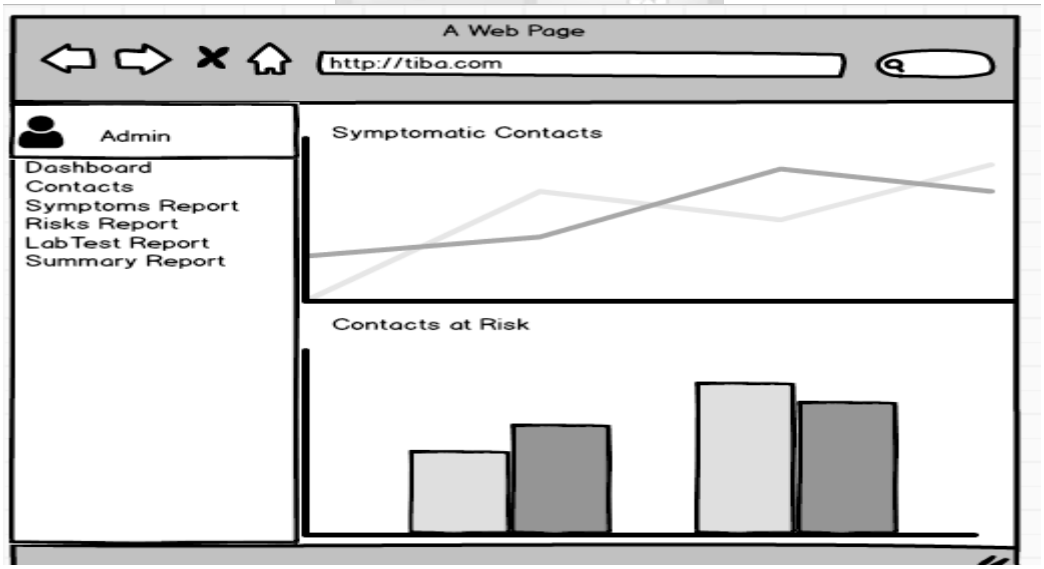


Figure D. 13 Web Dashboard Wireframe

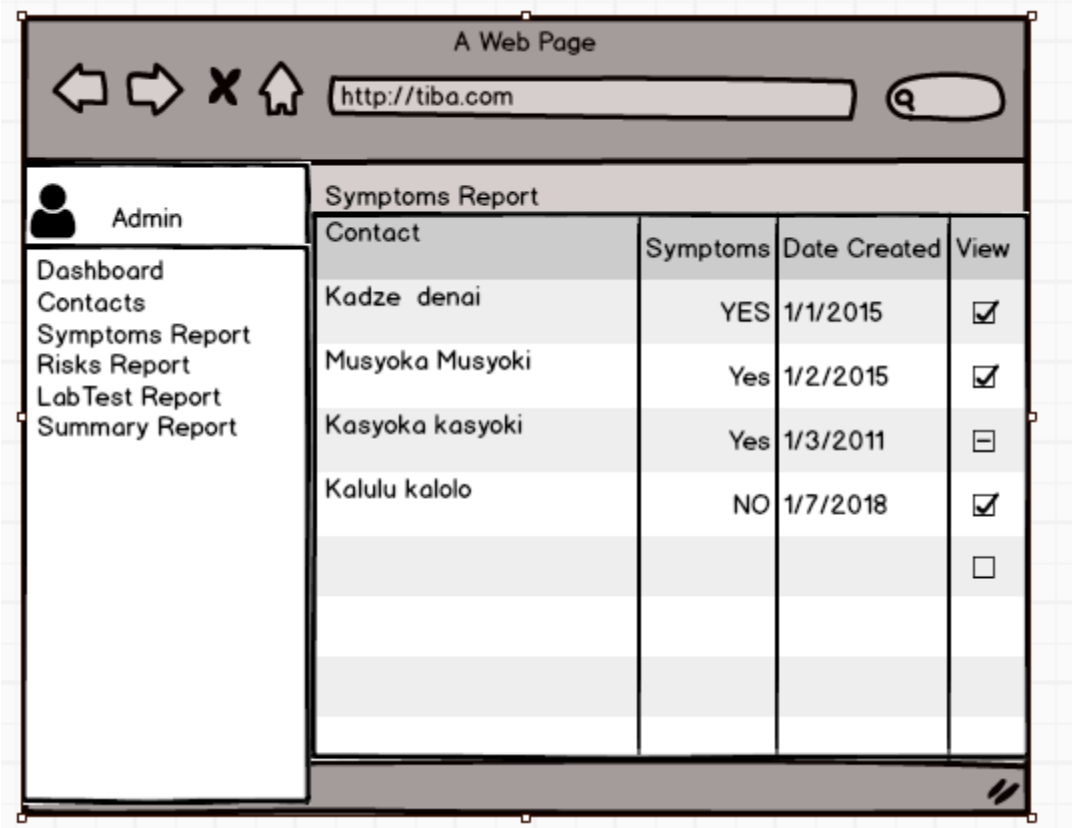


Figure D. 14 Symptoms Report Wireframe

Appendix E: Screenshots

USSD Screenshots

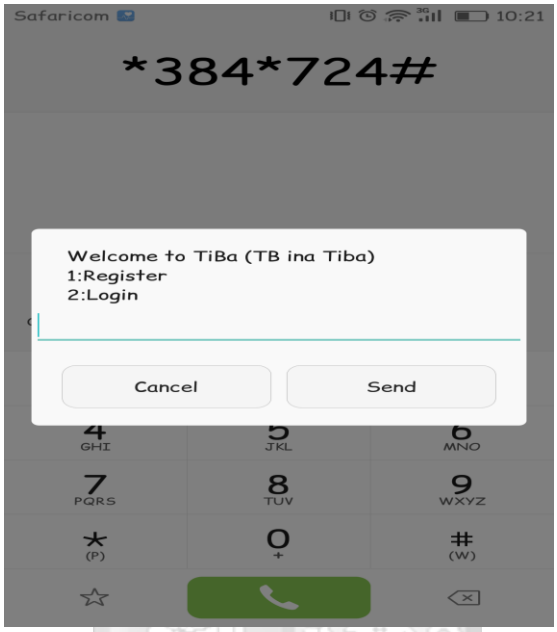


Figure E. 1 USSD Login Menu Screenshot

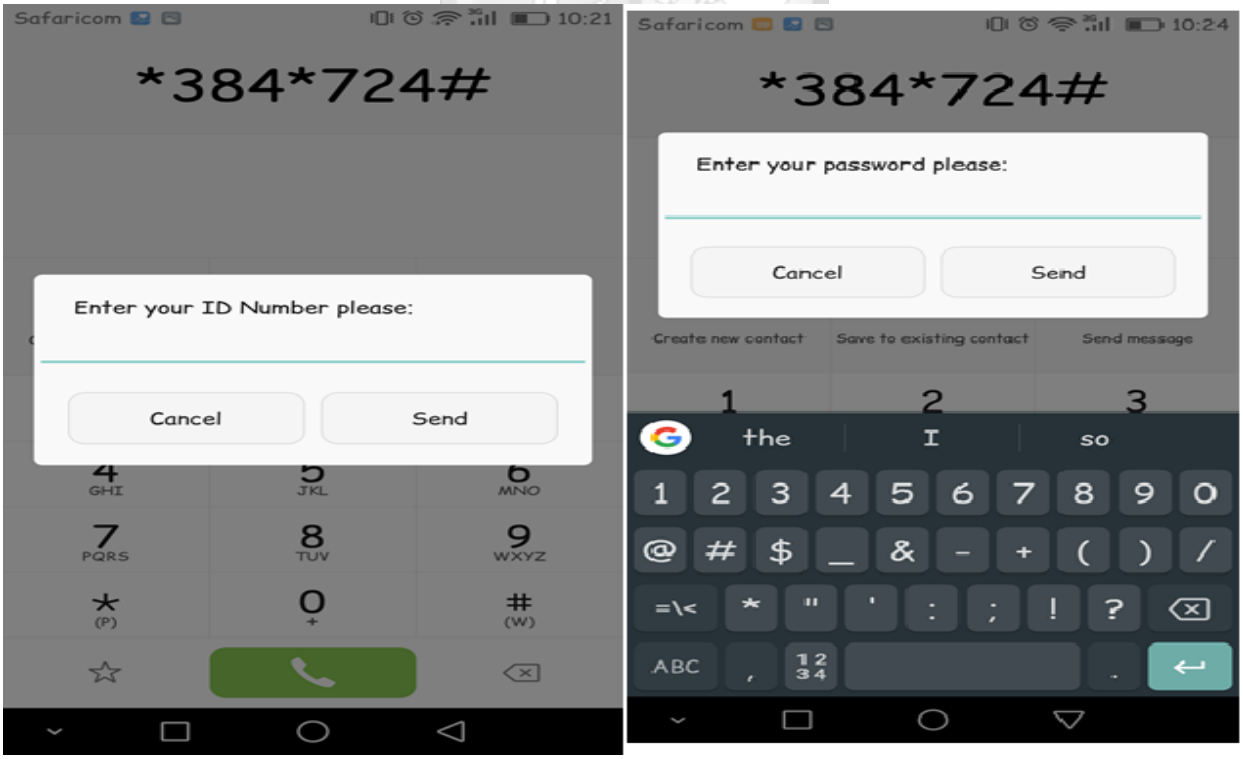


Figure E. 2 USSD Login Details Screenshot

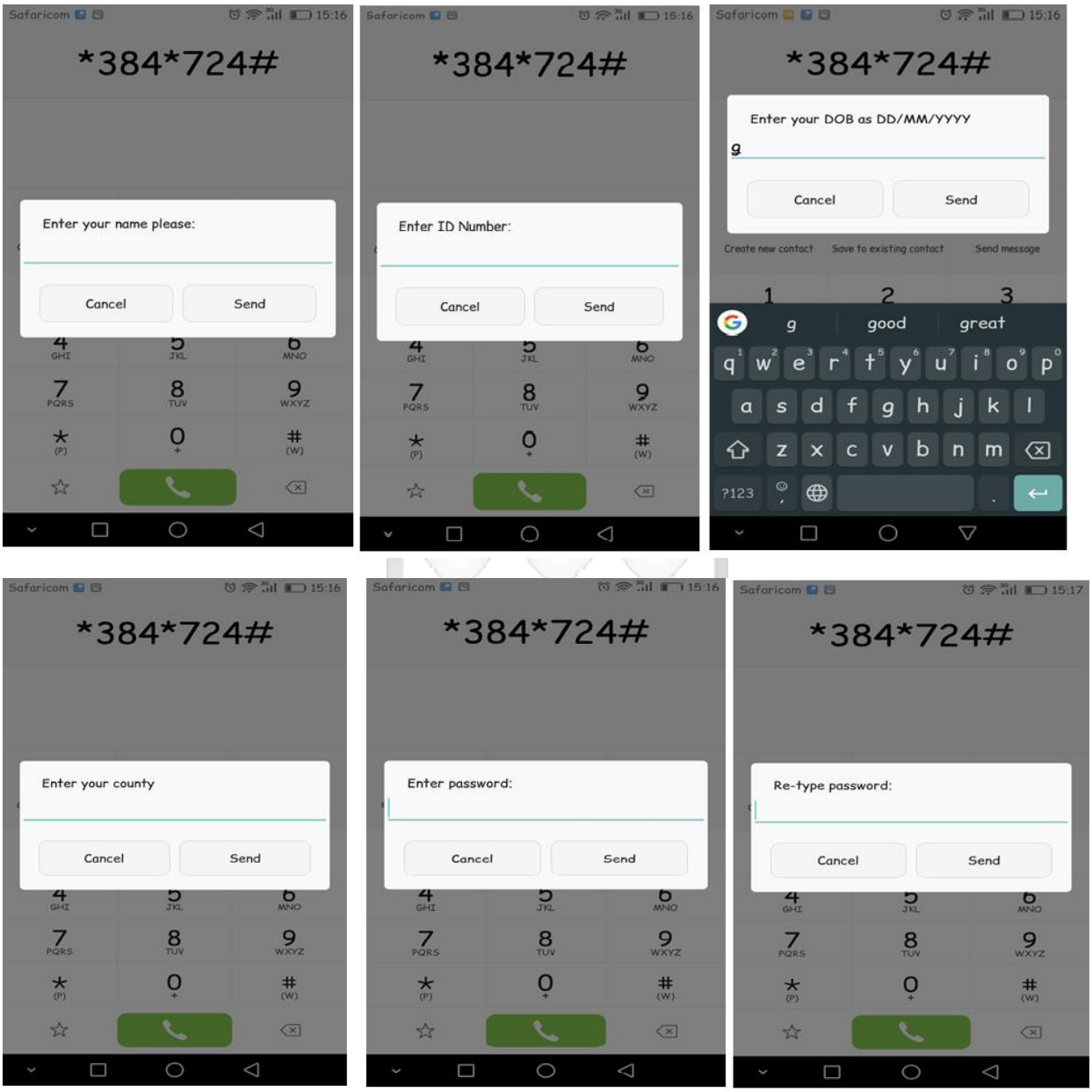


Figure E. 3 USSD Registration Details Screenshot

Android Screen Shots

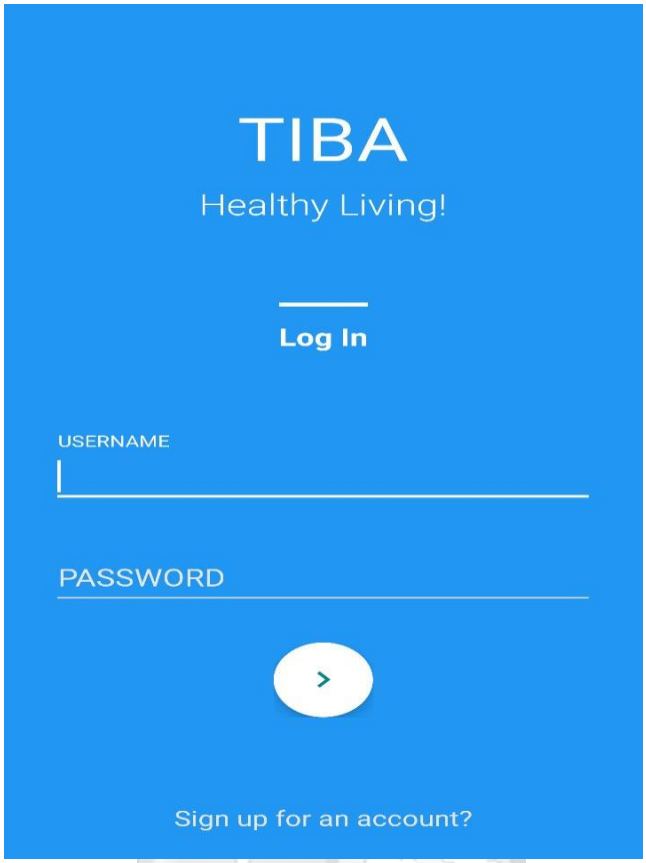


Figure E. 4 Android Login Screenshot

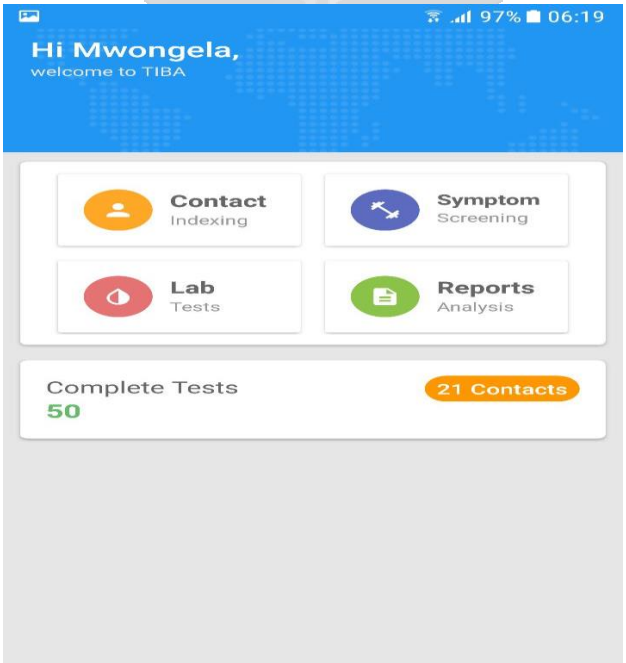


Figure E. 5 Android Main Menu Screenshot

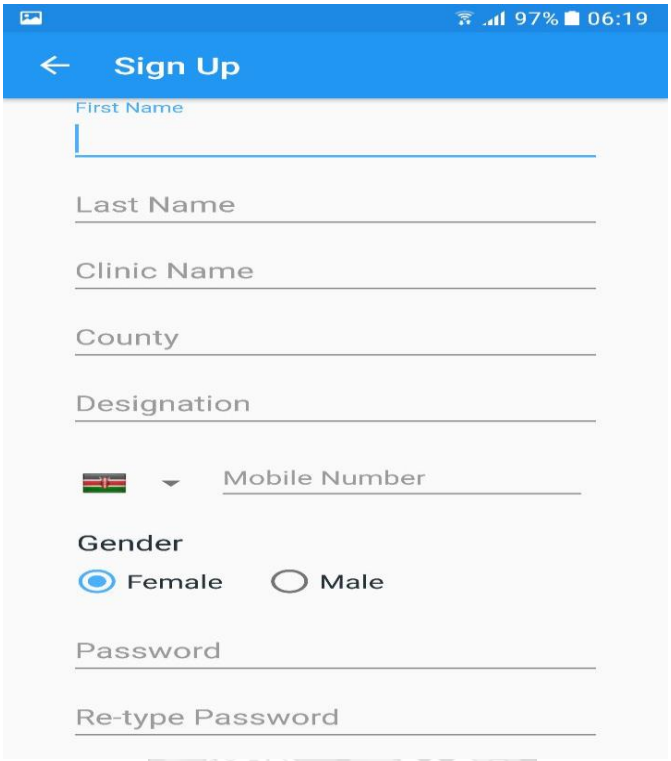


Figure E. 6 Sign-Up Sheet Screenshot

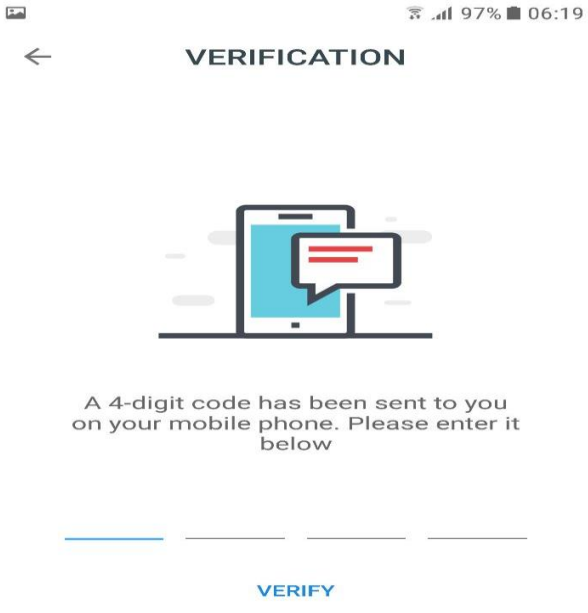


Figure E. 7 Verification Screenshot

Web Application Screenshots

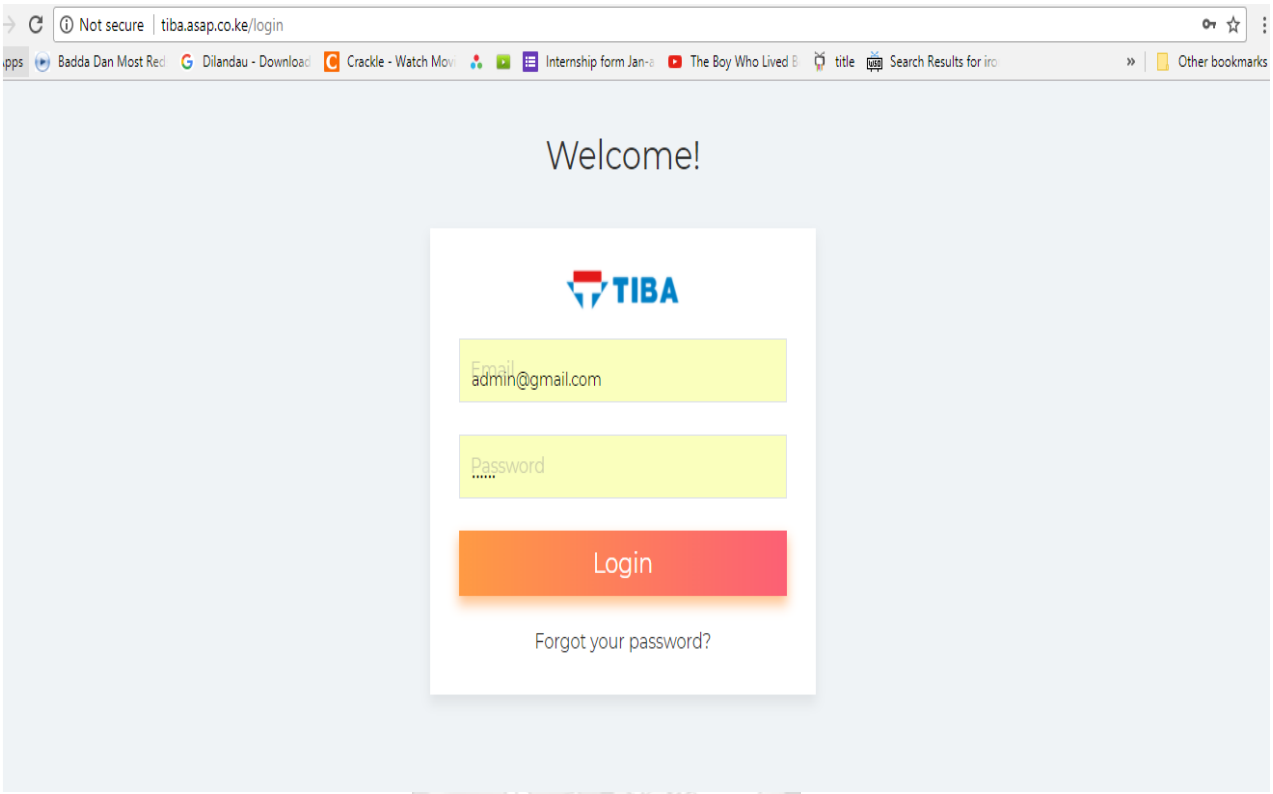


Figure E. 8 Administrator Login in the web application

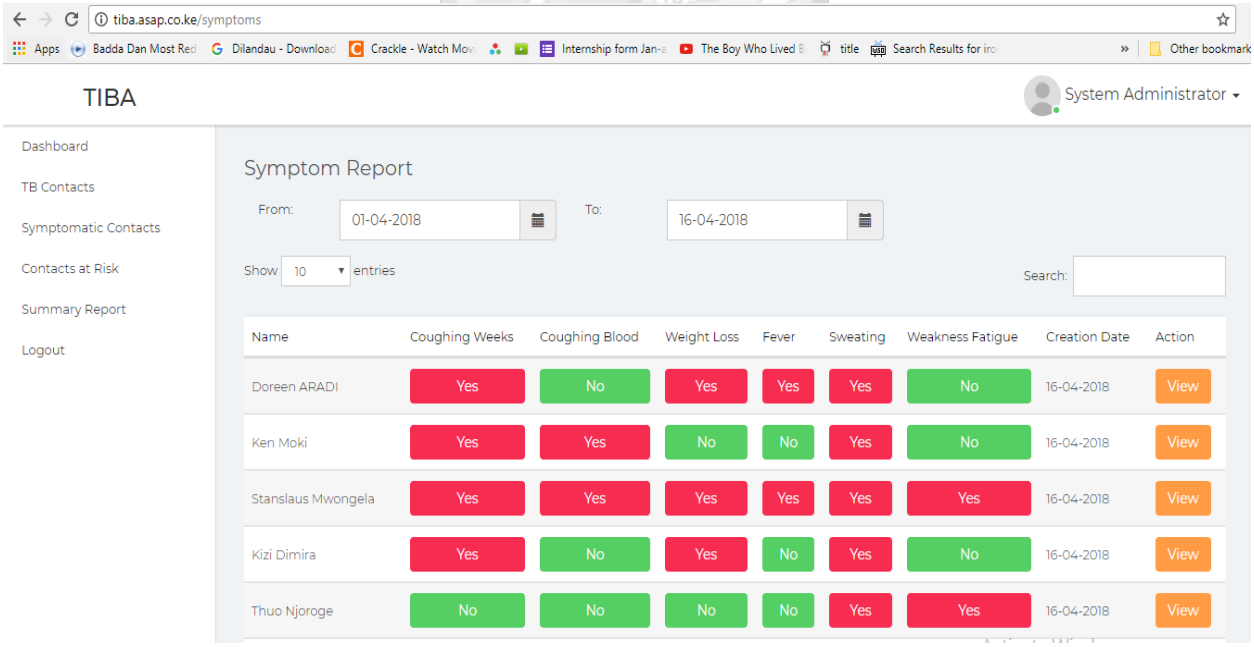


Figure E. 9 Symptoms Report Screenshot

Appendix F: Turnitin Report

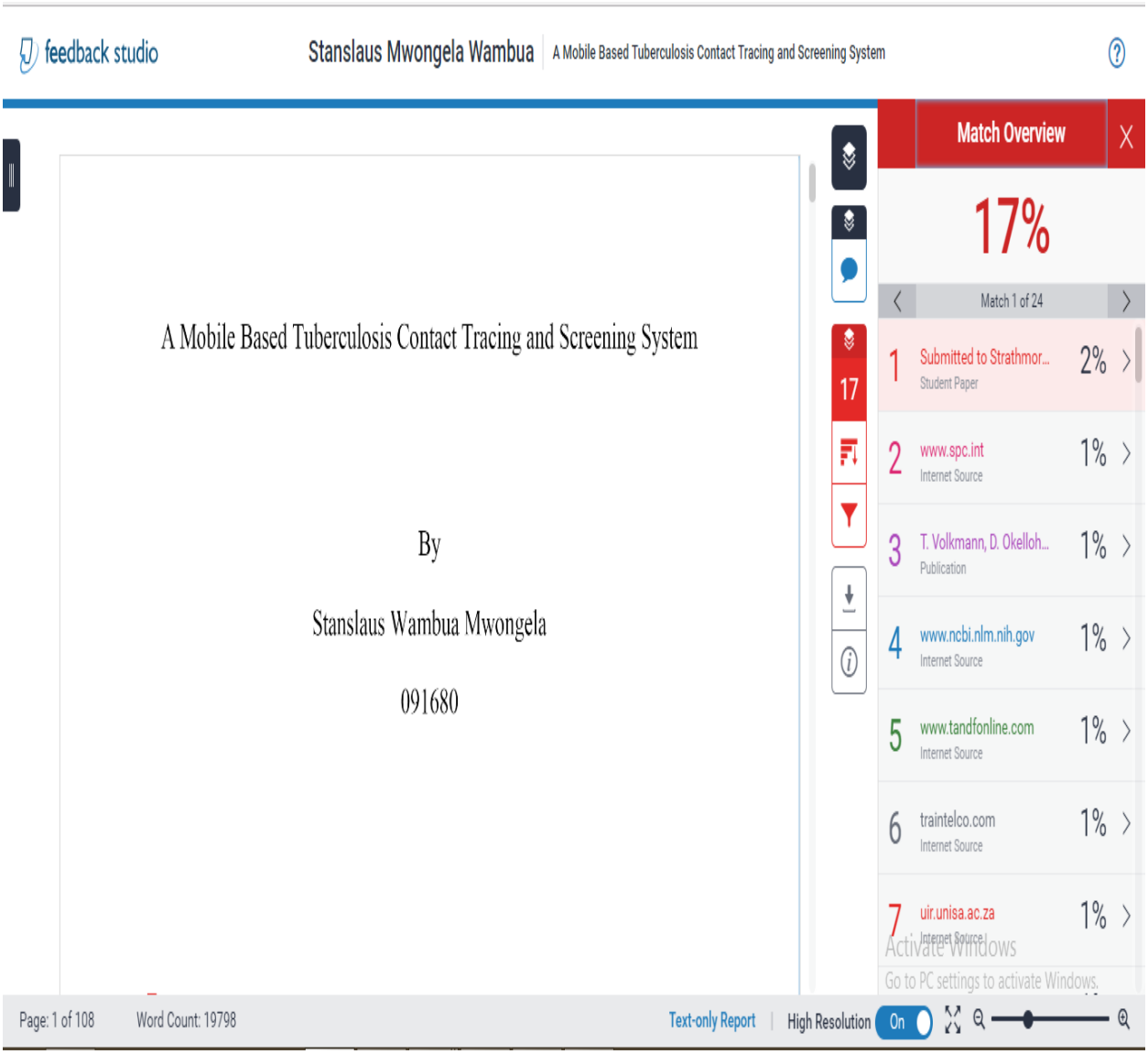


Figure E. 10 Turnitin Report