Tuberculosis Contact Tracing and Screening Application

By

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Declaration and Approval

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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Acknowledgement

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List of Abbreviations / Acronyms

Abbreviation/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

Abstract

The process of tuberculosis (TB) contact tracing and screening in Kenya follows immediately after a TB patient has been tested and confirmed to have TB in a TB Clinic. The TB patients is asked to fill a contact details examination form detailing his close contacts. A health worker will then go out into the community to locate and screen the contact, by asking the contacts a set of questions .Based on the answers given by the contact they may be referred to the nearest health facility for a TB test. The names of these tuberculosis suspects found are to be entered into the Suspect and Sputum Dispatch Register by data clerks until confirmed. This approach presents a number of challenges, first is the challenge of covering vast geographical locations with the limited number of healthworkers. The approach is also limited by inefficiencies in data collection, storage, retrieval and poor data quality, which can be attributed to collecting data on paper and storing the data on paper records (register). 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.

The proposed solution was a mobile-based TB contact tracing and system. Agile methodology was adopted as the software methodology for developing the system. The system included a front-end USSD application, a front-end Android application and a web dashboard. The 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. The USSD application allowed TB contacts to select their symptoms, risk factors and to check status of their screening results. The web dashboard presented the various analytics of the reports to the system administrator and TB policy officials.

Keywords: Tuberculosis contact tracing, contact screening, Android, USSD

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Chapter 1: 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. People who have pulmonary tuberculosis can infect others through droplet infection when they cough, sneeze or talk (World Health Organization, 2006). The prevalence of TB among close contacts of infectious patients can be about 2.5 times higher than 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).

Since the invention of the World Wide Web in the early 1990s, technologic advances have revolutionized daily life for people throughout the globe. Information communication technology is being increasingly used in health care settings, and has the potential to contribute significantly to health care provision, as regards both cost savings and quality of care (Blaya , Fraser , & Holt , 2010). A WHO resolution on eHealth in 2005 encouraged member states to collaborate and provide mutual support for its integration into health systems to improve health care, surveillance, and education. Although there remains a "digital divide" with patchy provision of information communication technology access globally, rapid advances in mobile telephone and wireless technology, and its increasing availability in otherwise resource-limited settings, are improving this situation (Simba, 2004). Integrating control programs with mobile and web-enabled applications offers the potential for significant improvements in TB service provision, with major 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) .

Information communication technology can support traditional contact tracing activity through text and mobile phone communication with possible contacts. Given that the aims of TB contact tracing are to disrupt the spread of disease and inform disease control efforts in a timely manner, the ability to rapidly collect and access high-quality data is a particularly notable benefit (Chapman, Darton, & Foster, 2013). In the field of sexually transmitted infection, there are some reports of the use of Internet-based partner notification using email to initiate contact. Electronic patient Registers have also been successfully used to improve TB surveillance in Massachusetts, US, through identification of patients being started on TB therapy who had erroneously not been notified as new cases. A system was set up where the EPR automatically generated an alert in a predefined scenario, for example, when a patient was prescribed pyrazinamide, had samples sent for TB culture, or had a test result suggestive of active TB. This also improved contact tracing efforts by more accurately reporting active cases, leading to more comprehensive and more 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 not yet adopted 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 in order to target a larger group and improve TB contact tracing, and screening activities in Kenya.

1.2 Problem Statement

The National TB Program in Kenya is falling short of reaching its objectives in combating TB. This can be attributed to inadequate human resources, low surveillance and monitoring of TB patients and their contacts, and deficiencies in coordinating data collection and reporting. Because of all or some of these shortcomings, TB rates have increased recently (MoH Kenya, 2015). In Kenya Healthcare workers care 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 locations. This study sought the development of a mobile-based system, which will help mitigate these problems and allow timely data collection to a central data store through mobile phone interaction without involving a TB focal person. With data submitted in real time to a central point, decision-making and production of reports can be instant and more effective.

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 included:

i. To analyze the challenges of the existing TB contact tracing and screening models in Kenya.
ii. To review related architecture, models and application used in TB contact tracing and screening.
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 challenges do current models for tuberculosis contact tracing and screening face to warrant a new system?
ii. What are the existing architecture, models and application used in TB contact tracing and screening.
iii. How can the mobile-based systems be used in TB contact tracing and screening?
iv. Can the developed system assist in TB contact tracing and screening?

1.5 Study Justification

Problems with management and analysis of patient data records create problems with monitoring and counteracting the effects of the diseases on the socio-economic landscape of the country. Tuberculosis contact tracing and screening, treatment adherence monitoring and remote data collection are areas that need particular attention in the fight against the spread of TB. In note of such problems, 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 USSD application that allows TB contacts to screen their symptoms for TB and combine their risk factors to determine priority of actions they should take. The system also included an Android application for TB case indexing and recording laboratory results of the TB patients. This system also incorporated a web dashboard for providing relevant reports and statistics to help improve decision making by health personnel.

1.6 Scope of study

Attention of this research was focused on Tuberculosis contact tracing and screening models currently in use in Kenya based on the guidelines developed Ministry of Health and international guideline 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 user of the solution is those who possess feature phones. The deliverable of this research was a mobile-based system and web application, which can be used for TB case indexing and collection of data from TB Contacts to facilitate contact tracing and screening. The system also supported in decision making on which contacts should visit a health Centre to be tested for TB, as well as in providing relevant reports and statistics to help improve decision making by health personnel.

Chapter 2: Literature Review

2.1 Introduction

This chapter covers the literature review. It starts by reviewing Tuberculosis contact tracing and screening, technology acceptance model, tuberculosis contact tracing and screening models and highlights the challenges being faced by the contact tracing and screening model in Kenya. A review of USSD 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

Tracing refers to the act of tracking, finding, locating, following, trailing or hunting down (Roget's International Thesaurus, 2011). It means seeking out, capturing or getting hold of someone. In the case of TB contact tracing and screening in this study, tracing refers to following up the TB patients with the expectation of identifying and screening contacts at risk of contracting TB (Kovarik, 2010). This process follows immediately after identification of a TB case index (source patient) usually through smear positive results (Kabongo & Mash, 2010). Contact tracing serves several functions (Mulder et al 2011): It identifies persons with TB disease or LTBI among the contacts of a TB patient and provides potential for prompt and adequate follow-up and treatment (Zellweger, 2010). It also traces and identifies the contacts of contacts. That is acknowledging that the new TB patients also have contacts that must be found and tested. It reduces further TB transmission in the household and workplace. It reduces morbidity and mortality due to TB among the newly infected persons.

Screening is defined as selection, inspection, assessment, investigation, examination or testing (Roget's International Thesaurus, 2011). Screening also means studying, researching, scrutinising, analysing or reviewing something. In the context of the TB contact tracing and screening programme, contact screening is the process of finding, testing, treating and notifying persons who might have latent TB infection (LTBI) or TB disease as a result of recent contact with a person diagnosed with the disease (Zellweger, 2010). After the diagnosis of the TB, the health institutions must institute screening of the contact(s) within the earliest time and fastest means.

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, they have to fill a contact examination form detailing people that they have had close contact. Contacts might include for example, family members, prolonged contacts and co-workers, and particular attention is paid to HIV-positive individuals. A health worker will then go out into the community to locate and screen the contact. Contact screening entails asking each contact a set of questions to determine if they have symptoms of TB. The responses are recorded in the contact examination form (MoH, 2016).

This investigation is required to start within three working days from the date of registration of the TB patient to identify infected contacts. The contact evaluation entails asking the contacts a set of questions. Based on the answers given by the contact they may be referred to the nearest health facility for a TB test. The names of these tuberculosis suspects found are to be entered into the "Suspect and Sputum Dispatch Register", until confirmed. Close contacts of MDR (Multidrug-resistant) -TB patients have been known to have high rates of MDR-TB, and should be followed up for at least two years (MoH, 2016).

2.3.1 Documented Case of TB Contact Tracing and Screening in Kenya

A contact tracing intervention was developed and piloted at three facilities in Kisumu County from November 2014 to April 2015. The sites were purposely selected based on high TB burden and the existence of a community health strategy utilizing CHVs. Pilot activities were embedded within the Kenyan MoH's routine contact tracing program and no alterations were made to existing MoH forms (Volkmann, Okelloh, Agaya, & Cain, 2016). The intervention introduced a package of changes to the contact tracing process, including a pilot contact tracing register and several modified practices at study facilities. The contact tracing register included variables abstracted from facility TB registers and MoH forms used for routine contact tracing, variables collected at facilities and clinics, and notes from the CHVs' notebooks.

Other intervention components included retraining CHVs on contact tracing procedures, designating a TB clinic nurse at each facility who was responsible for updating the routine MoH TB register to also maintain the pilot contact tracing register, providing the nurse with a monthly compensation of approximately US$70 for undertaking this responsibility, and holding monthly progress meetings to review and update CHVs on the progress of their contact tracing work (Volkmann, 2016). It was noted that simple programmatic interventions can potentially improve the effectiveness of contact tracing and should be considered, especially in areas 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 (EPRs) have been introduced in many countries in recent years. They have the potential to improve many aspects of clinical practice, including prescribing, patient follow-up, chronic disease management, and adherence to clinical guidelines. However, there are also potential challenges, including underestimation of time commitment by physicians, the need for expensive ongoing technical support, and concerns about the maintenance of patient confidentiality (Lau , et al., 2012) .With increasing availability and reliability of Internet access globally, there is recognition that EPRs could also contribute significantly to contact tracing.

EPRs have been successfully used to improve TB surveillance in Massachusetts, US, through identification of patients being started on TB therapy who had erroneously not been notified as new cases. A system was set up where the EPR automatically generated an alert in a predefined scenario, for example, when a patient was prescribed pyrazinamide, had samples sent for TB culture, or had a test result suggestive of active TB. This also improved contact tracing efforts by more accurately reporting active cases, leading to more comprehensive and more rapid identification of potential contacts (Calderwood , Platt, & Hou , 2010).

In Illinois, US, EPRs have been used to improve compliance with TB screening programs in patients commencing biologic therapies with tumor necrosis factor antagonists (Hanson, et al., 2013). All patients with an electronic prescription for a tumor necrosis factor antagonist were flagged as requiring screening tests for TB and hepatitis B, as well as routine full blood count and liver function tests. With increasing use of immunosuppressive therapies for many inflammatory conditions, such an approach could be extended to a range of settings.

2.4.2 Contact tracing and screening using web-based strain typing

The development and refinement of strain typing methodologies offers the potential for improved contact tracing when used alongside traditional contact investigation activity (Crawford , 2003). *Mycobacterium tuberculosis* isolates can be typed according to the number of repeat sequences at various sites or loci within the genome: the MIRU-VNTR (mycobacterial interspersed repetitive units-variable numbers of tandem repeats) method uses 24 loci. Each isolate is given a 24-digit code specifying the number of repeats at each locus; the codes are highly specific for that isolate and hence can be used to provide evidence for or against transmission from person to person. Strain typing data allow rapid identification of potential clusters of related cases, enabling early initiation of control measures (Tardin, Dominice, & Janssens, 2009).

The utility of strain typing is supported by the development of large web-based national and international strain registries (Weniger, Krawczyk, Supply, Harmsen , & Nieman, 2012). This allows comparisons to be made between strains, for local contact tracing, and for wider epidemiologic investigations, for example the MIRU-VNTR plus tool (Shabbeer, Ozcaglar , Yener, & Bennett , 2012). Databases containing full genomic sequencing data can also be used as research tools to explore genotype-phenotype associations, for example, the open access *M. tuberculosis* genome divergence database. (Vishnoi , Srivastava, Roy, & Bhattacharya , 2008). However, the increasing availability of Internet access worldwide can have unintended consequences: Ohkado et al (2009) described an outbreak of TB in Tokyo, which was investigated using strain typing. They concluded that transmission was most likely to have occurred in Internet cafés.

2.4.3 Contact tracing and screening through Social network analysis

The success of a network-informed approach to contact tracing and screening sexually transmitted infections (STIs) led to its use in TB control, in particular for its potential to identify how TB cases are connected to one another and to identify and prioritize contacts for evaluation (Klovdahl , 2015). Social network methods, alone and in combination with conventional and molecular epidemiology, have been used to examine TB clusters and outbreaks both retrospectively and prospectively in Aboriginal settings (McElroy , Rothenberg, Varghese, & Woodruff, 2016). Network methods have also clearly documented that locations are key to the evaluation of TB transmission. Focusing on locations and location-based contacts has been shown to link cases and contacts which otherwise do not fit the traditional expectations of contact interactions (Cook , et al., 2007). With respect to Aboriginal TB control, network analysis has helped to understand outbreak boundaries, locations of transmission and the risk of TB in contacts in remote communities in Manitoba. These methods were also used to investigate a developing TB outbreak involving Aboriginal persons 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 systems (GIS) and global positioning systems (GPS) are tools used to visualize data involving distance and location. These techniques have been used to examine the distribution of TB cases, risk factors for acquiring disease, and the relationship of TB to the surrounding environment and health care system (Moonan , Bayona , Quitugua, Oppong , & Dunbar , 2014) .In lower incidence settings, TB rates are most often attributed to immigration patterns. However, it is interesting to note that investigators have clearly demonstrated that it is the deprivation of certain ethnicities, not only high prevalence immigration backgrounds, which influences TB disease rates (Moonan et al, 2014).. There are no published studies looking at GIS/GPS specifically in Kenyan communities. However, the results available to date, particularly where they relate to the determinants of health may be highly relevant and applicable in some communities.

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

Current molecular epidemiology methods for investigating TB include simple DNA fingerprinting techniques such as RFLP/PFGE and more advanced techniques based on sequencing, such as MIRU-VNTR. While these methods can readily identify clusters of related cases, they cannot provide further detail, such as the resolution of individual transmission events within a cluster. Rapid advancements in DNA sequencing technology have made whole genome sequencing of bacteria like those that Mycobacterium tuberculosis quite tractable , a genome can be sequenced in as little as 1 day for $50_$250 _ and the resulting data can now be used to understand transmission dynamics at a much higher resolution. (Gardy , Johnston, & Ho Sui , 2011)

In a recent TB outbreak investigation in Canada, genomic data from the outbreak organisms was able to identify transmission events, individuals acting as super spreaders, and confirm parallel related, yet distinct, outbreaks within the community (Gardy , et al., 2011). This investigation integrated clinical data, social network analysis and genomics to better characterize a TB outbreak that had significantly affected community members. It also confirmed that social factors played a larger role in the 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 points out that this is partly caused by inadequate human resources, low surveillance and monitoring of TB patients and their contacts, and deficiencies in coordinating data collection and reporting (WHO, 2013) . Problems with management and analysis of patient data records create problems with monitoring and counteracting the effects of these diseases on the socio-economic landscape of a country. TB patient and contact tracing, treatment adherence monitoring and remote data collection are areas that need improvement.

Kenya contact tracing and screening model compare to that of Botswana where the current common methods of data collection and patient management are manual and paper-based. A number of challenges faces this system; this include; the 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). The inadequate health care workers are themselves 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 means the already limited health care workers have to travel long distances from their base locations to monitor TB contacts. Travel is expensive and time-consuming.

Poor data records and distribution- Once the health care workers locate the close contacts, they interview them; screen them for TB, and all the information about the contact is captured into paper documents. The paper documents are brought back to the health facility and transferred into a database by data clerks (MoH, 2016) .This has resulted in poor data records since records sometimes go missing. In addition, the information is not centralized, meaning that it can only be accessed from one location.

Analysis of data - Since the system is paper-based with poor records and not centralized, it is very difficult to analyse the data for decision-making and report-creation. In addition, since a TB focal person makes decision-making, it is prone to human error.

2.6 Documented Contact Tracing and Screening Systems

Several contact tracing and screening systems are presented and analysed 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 has a mobile-phone based interface on the side of the TB contacts and a web interface on the side of health workers. The system collects data through interacting with a TB contact. The data is then stored in a centralized database. Once the data is collected, the system helps in deciding whether to refer the contact for a TB test. The system then initiates a session with the user, during which it presents some questions to screen the user for TB. Depending on the answers to these questions (whether they show potential TB symptoms or not, or if they are at risk for contracting the disease), the user may be referred to a local clinic for a TB test. The system also assisted health workers in doing follow ups with referred contacts in case they do not respond in a given timeframe, to evaluate whether they indeed went for a test and whether they have TB or not. A web application front-end was provided to allow the health workers to access the stored information, create and view reports (Makhura et al., 2014).

The systems had multiple interfaces to work with different devices and users. The mobile phones interacted with the system through the GSM networks. The standard mobile phones used the USSD protocol to communicate with the system. Messages were sent to the USSD gateway through this network, which passed them on to the server. The USSD gateway was used to interface the applications and database server with 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.

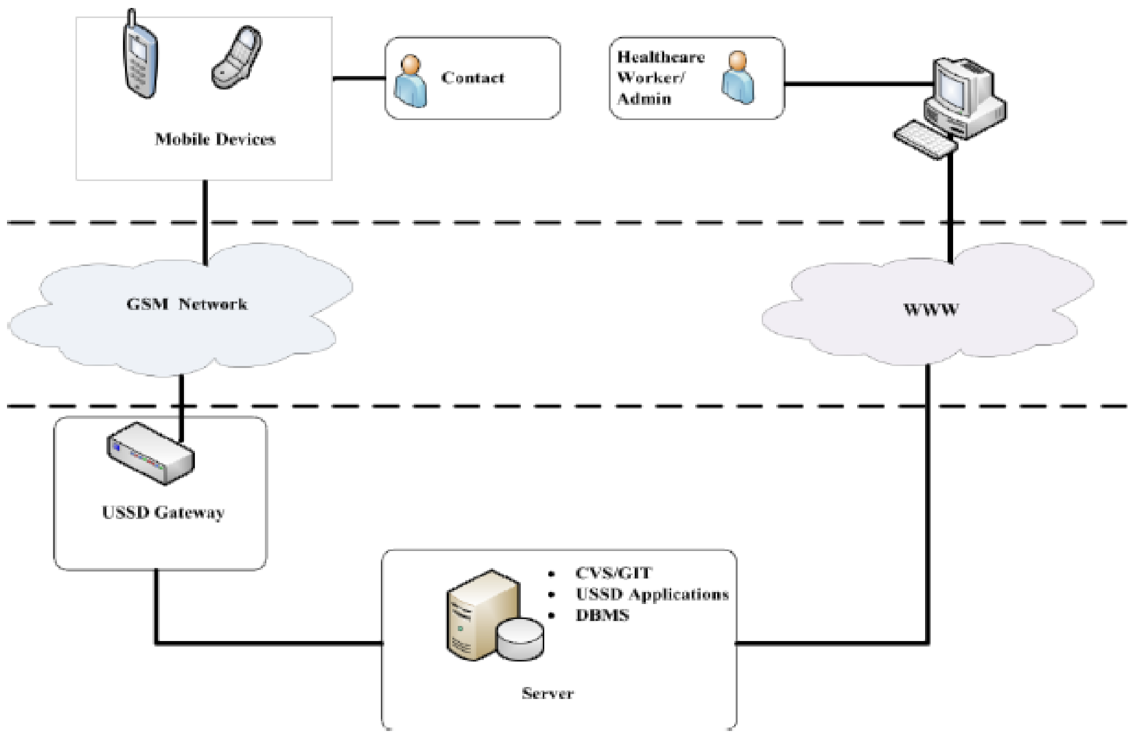


Figure 2. 1 Botswana's USSD TB Contact Tracing and Screening architecture

Adapted from Makhura et al., (2014).

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

In China, tuberculosis surveillance is organized through a nationwide network of about 3200 disease control centers or TB dispensaries. In 2005, an electronic Tuberculosis Information Management System (TBIMS) started to be phased in nationwide to replace paper recording. Since then the TBIMS has become more elaborated and collects key information on TB cases notified (confirmed or under evaluation) in TB care facilities. Data are exchanged in real time with the Infectious Disease Reporting System, which covers the country's 37 notifiable diseases. By 2009, the TBIMS achieved countywide coverage (WHO, 2015).

A paper-based surveillance system ran in parallel with the TBIMS from 2005 to 2008 and was discontinued in 2009, by when the difference between TB cases captured on the two systems had diminished and the TBIMS was able to capture almost all TB cases notified in the TB. The TBIMS is accessible to authorized users at every level of the TB network through a password-protected website. Health personnel from provincial and prefectural TB health facilities were trained when the system was introduced; these staff in turn trained other workers at county level through a cascade system. The sheer scale of the data handling and the intricate functions that the China TBIMS performs makes it stand apart from the electronic information systems for TB adopted in other countries .The main limitation of this system lies in customizing it to meet the different guidelines of contact tracing in different countries. Figure 2.3 shows China's Tuberculosis Management System Architecture.

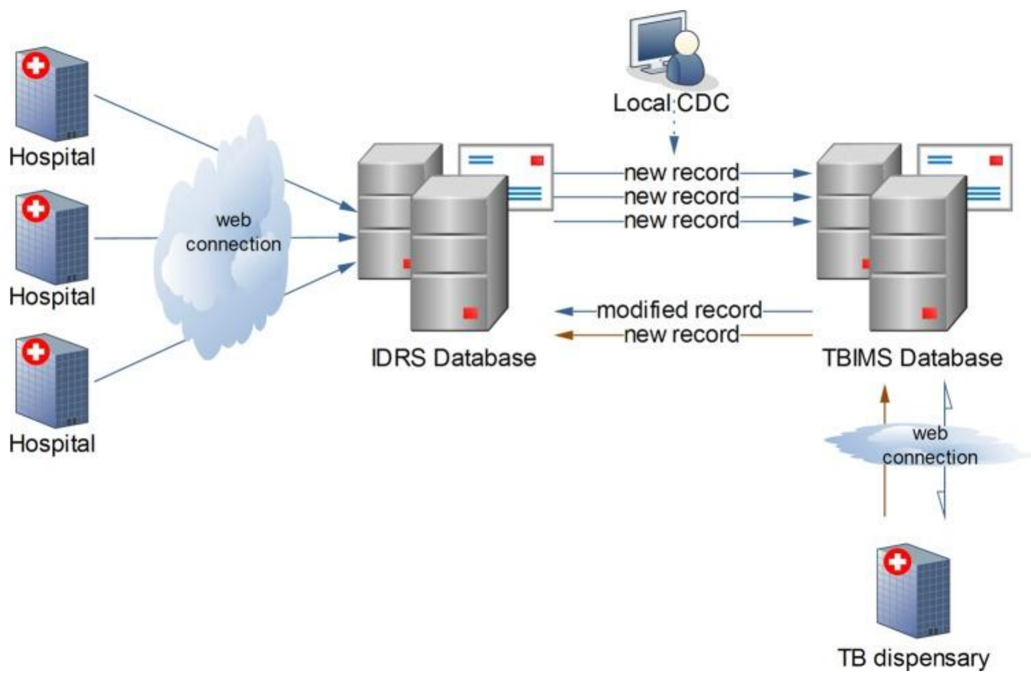


Figure 2. 2 China's Tuberculosis Information Management System Architecture

Adapted from WHO report (2015

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

Management Sciences created e-TB Manager for Health (MSH) through a USAID-funded programme, Systems for Improved Access to Pharmaceuticals and Services (SIAPS). E-TB Manager was conceived as a web-based system to centralize information on diagnosis, treatment, medicines and laboratory use. In terms of software architecture, e-TB Manager has the following specification; database is based on MySQL 5.6+, language is based on Java 1.6+ using JEE 1.5 and the application server is based on JBOSS AS 4.2.3.GA .(Management Science of Health, 2008).

The system can generate indicators based on the activity data of diagnosis, treatment, medicines and laboratory use. By mid-2015, MSH had supported the deployment of e-TB Manager in over 2500 sites located in 10 countries in Africa, Asia, Latin America and Eastern Europe. Close to 400 000 patient records are stored in individual format in all sites combined. As is the case for any information system, electronic registers require regular and careful updating of data to serve their clients' needs. However, experience with the use of e-TB Manager has shown that this investment bears substantial gains, such as reducing the time that supervisors need to spend to collect data on-site, thus freeing more time for them to devote to other aspects of programme monitoring. The main limitation of this system is lies in infrastructure, there is need to develop PC-based provincial databases (Management Science of Health, 2008). Figure 2.4 shows a snap shot of case search results page of e-TB manager.

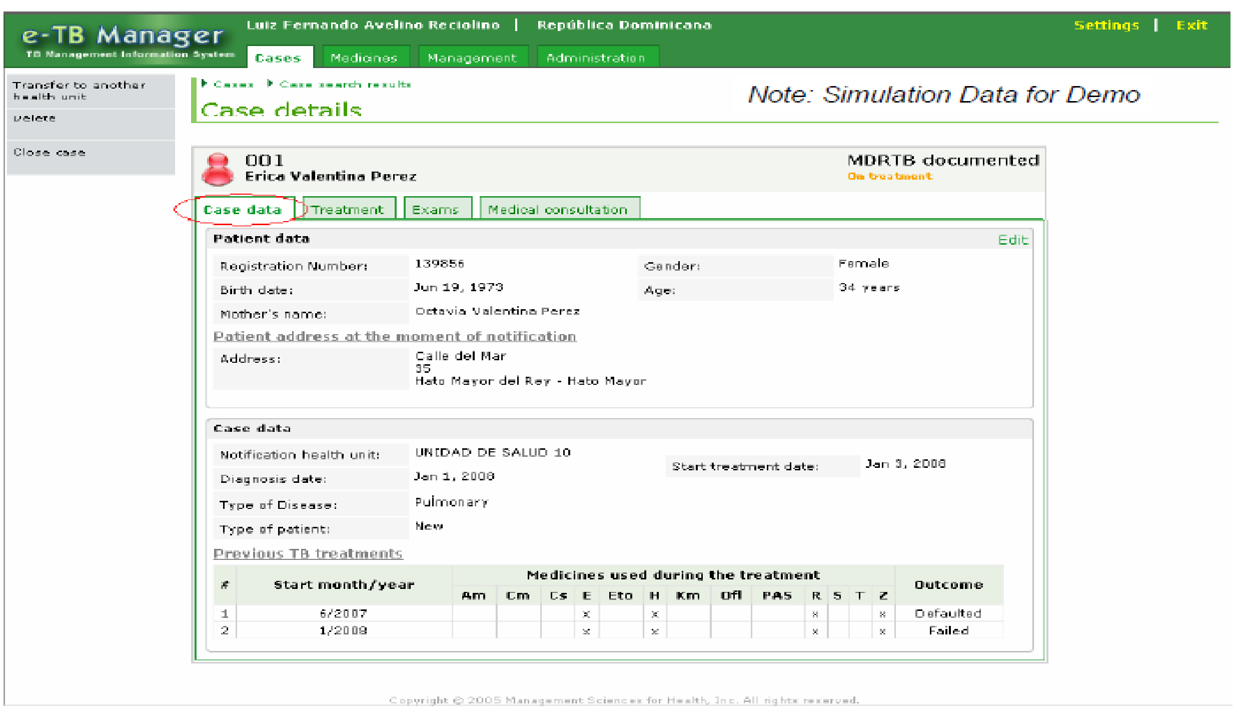


Figure 2. 3 e-TB Manager

Adapted from Management Science of Health (2008)

2.7 Review of 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 2.5 illustrates the USSD Architecture.

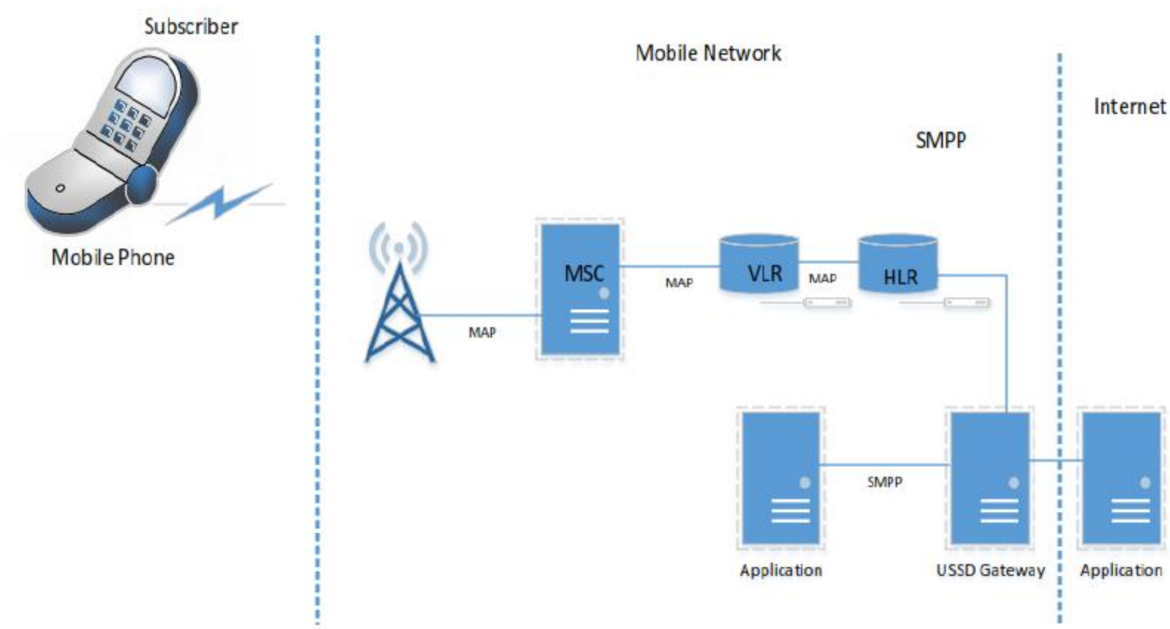


Figure 2. 4 USSD Architecture

Adapted from Tata Teleservices Ltd, 2007

2.7.2 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 2.6 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.

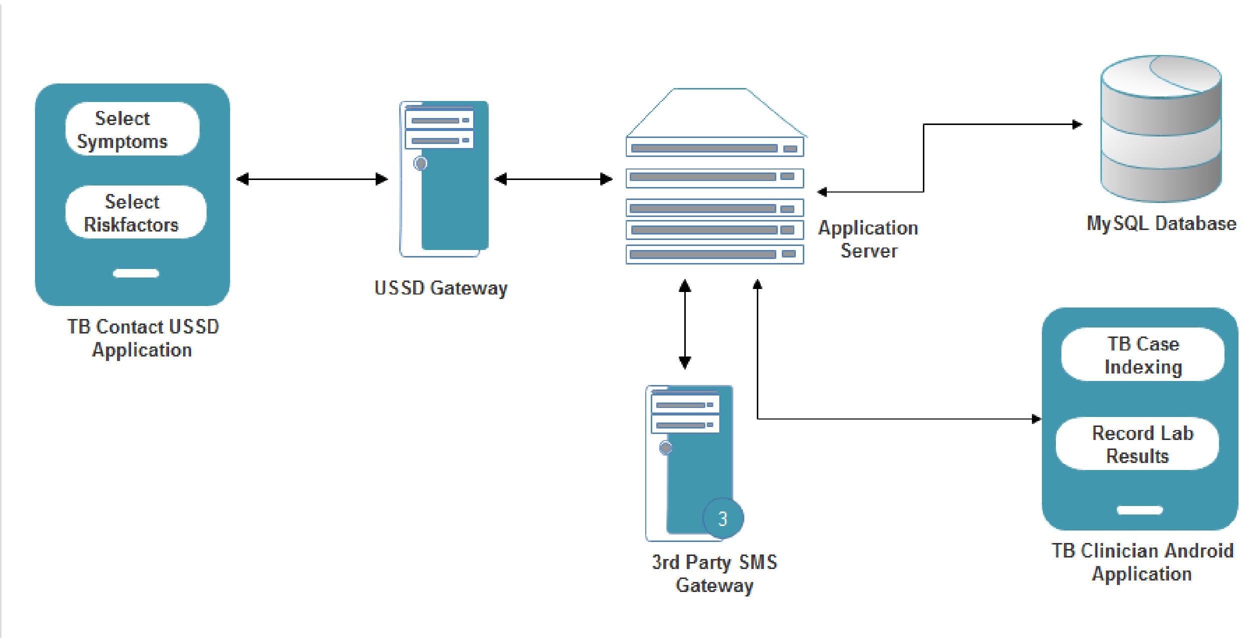


Figure 2. 5 Conceptual Framework

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 points out that this is partly caused by inadequate human resources, low surveillance and monitoring of TB patients and their contacts, and deficiencies in coordinating data collection and reporting (WHO, 2013) . A mobile-based system can help in eliminating some of this challenges identified. The proceeding chapter will help discuss how this mobile system can be designed, developed, implemented and tested.

Chapter 3: Research Methodology

3.1 Introduction

This chapter presents the methodology 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 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 application followed five main phases, which include the Planning phase, Requirement analysis phase, Design phase, Building phase and the Testing phase.

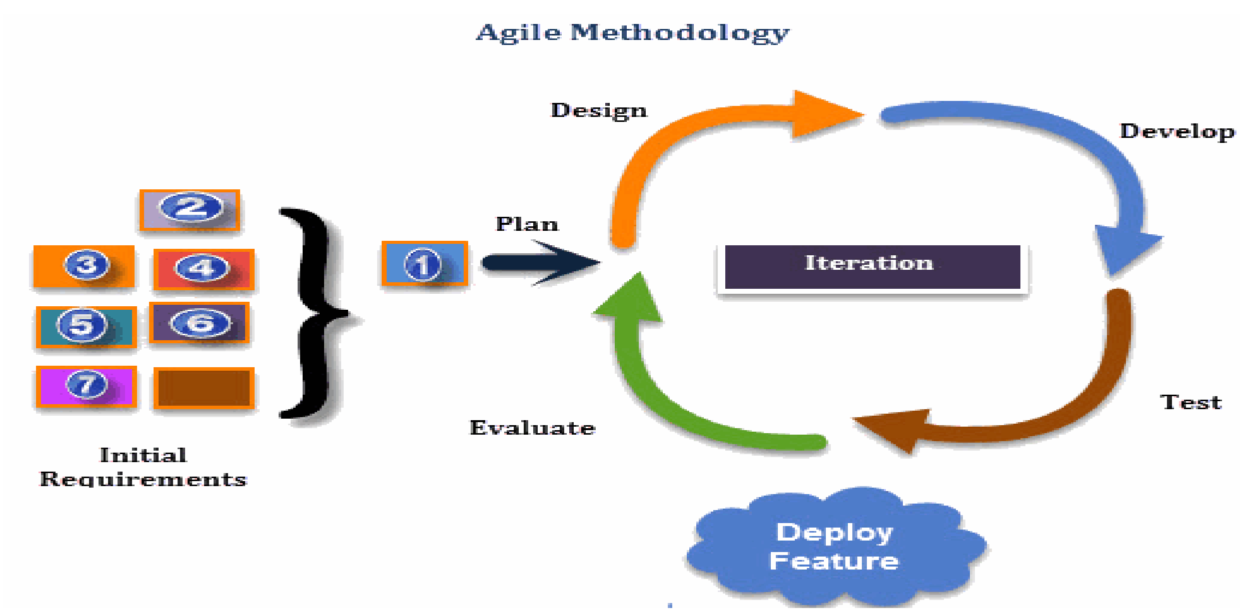


Figure 3. 1 Agile Methodology (Six Sigma,2017)

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 TB contact tracing and screening.

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 application.

d) Sample Size

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

e) Data Collection

Data collection was conducted through interviews, questionnaires, observation and data inventorying. 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. This aided in getting precise information on the requirements of the application 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 to understand the challenges experienced with the current TB contact tracing and screening approach and demand for the application. The questionnaire at Appendix A was drafted and issued after the development of the application for the purposes of validating the developed solution.

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 analyse 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 to develop. 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.

c) Database

The USSD application and Android Application communicated with a MySQL Database Management System (DBMS) and an implemented back-end API. 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. User Tests: this test were carried out on the developed application to measure user satisfaction and collect feedback for refining the prototype. A questionnaire was used to measure user satisfaction and collect feedback.
ii. 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.
iii. Validation: users of the application were be able to test whether the application worked, as it should. User‘s satisfaction was used to verify the system.

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 both the front –end and back-end sides of the application 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. 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 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.

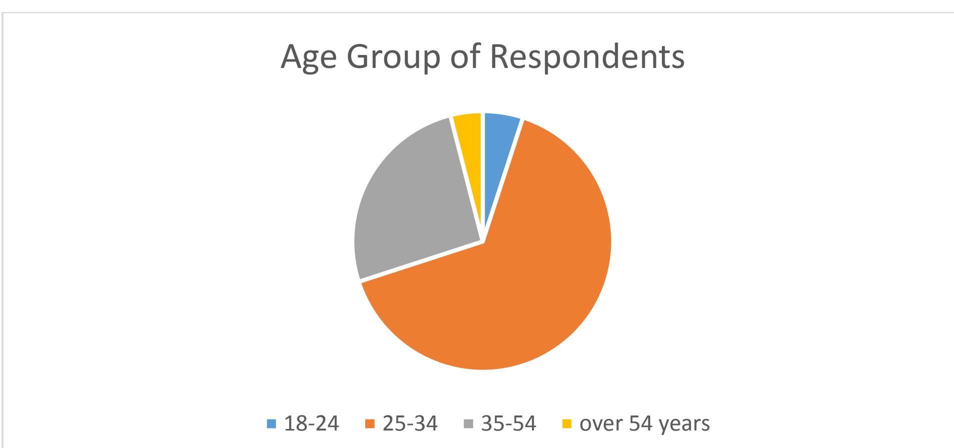


Figure 4. 1 Age Group of Respondents

4.2.2 Number of contact tracing and Screening activities the respondents have undertaken

Figure 4.2 shows the number of contact tracing and screening activities the 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 Respondents have used

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. 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.

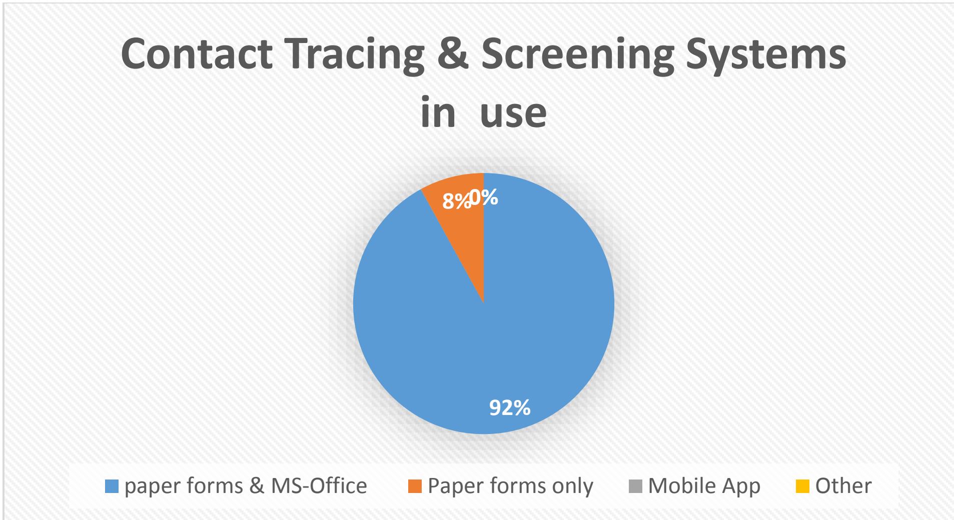


Figure 4. 3 Contact tracing and screening systems

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.

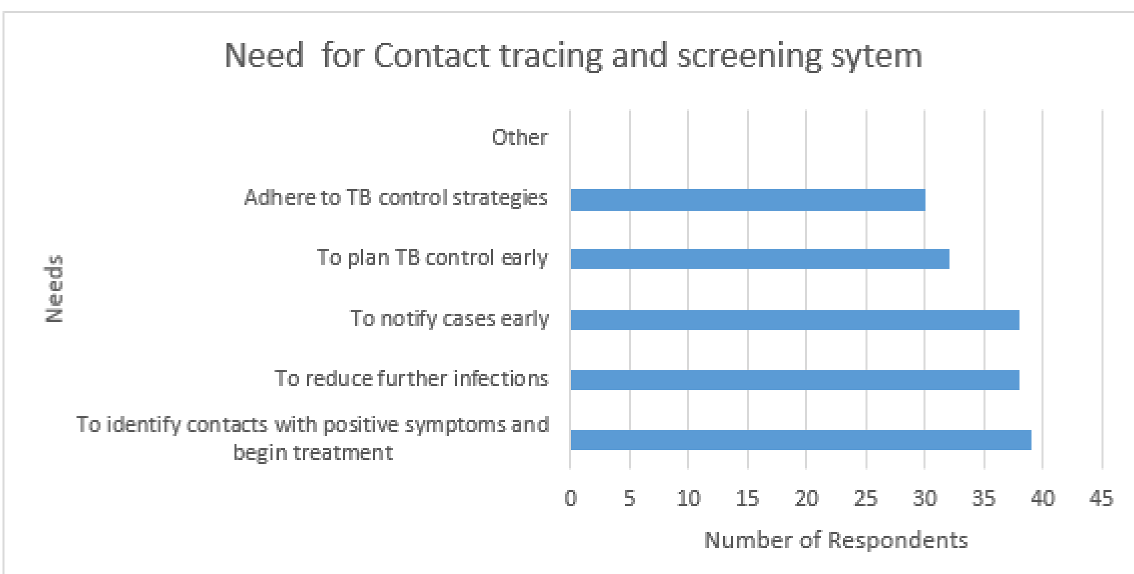


Figure 4. 4 Need for Contact tracing and screening system

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

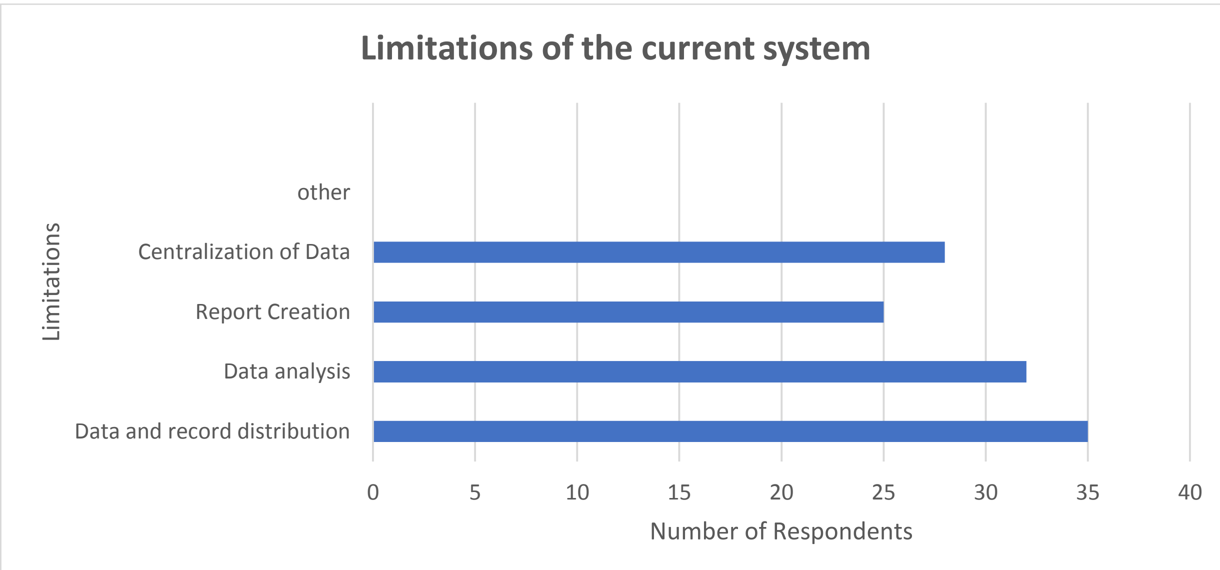


Figure 4. 5 Limitations of the Current System

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 results 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

Functional requirements are the functions, basic processes and capabilities that the implemented system should be able to execute. They include; Select Symptoms (users are able to select their symptoms) ,Select risk factors (users are able to select their risk factors), Record LabTest Results(TB clinician is able to record the laboratory test results of contacts confirming they have TB or not), Manage services (The administrator is able to add, delete or update a service), Check analytics (The administrator, care givers and TB policy officials are able to view the summary of TB results of the contacts) and 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

These are qualities that a system can do without but are desired in order to make the system interactive, user friendly and easy to use. 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.

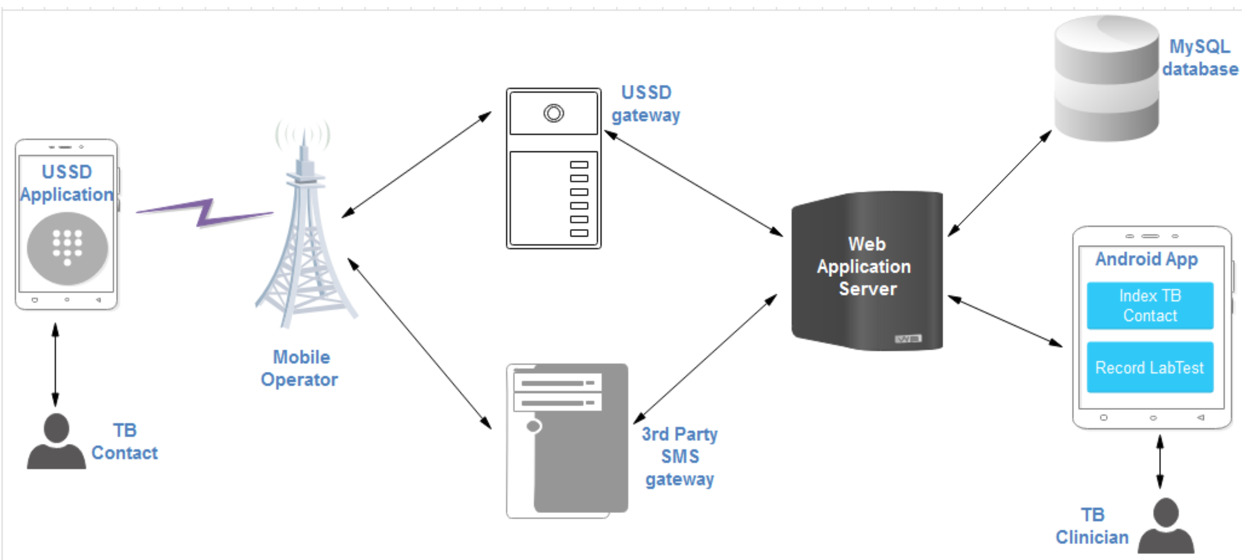


Figure 4. 6 Proposed System Architecture

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.

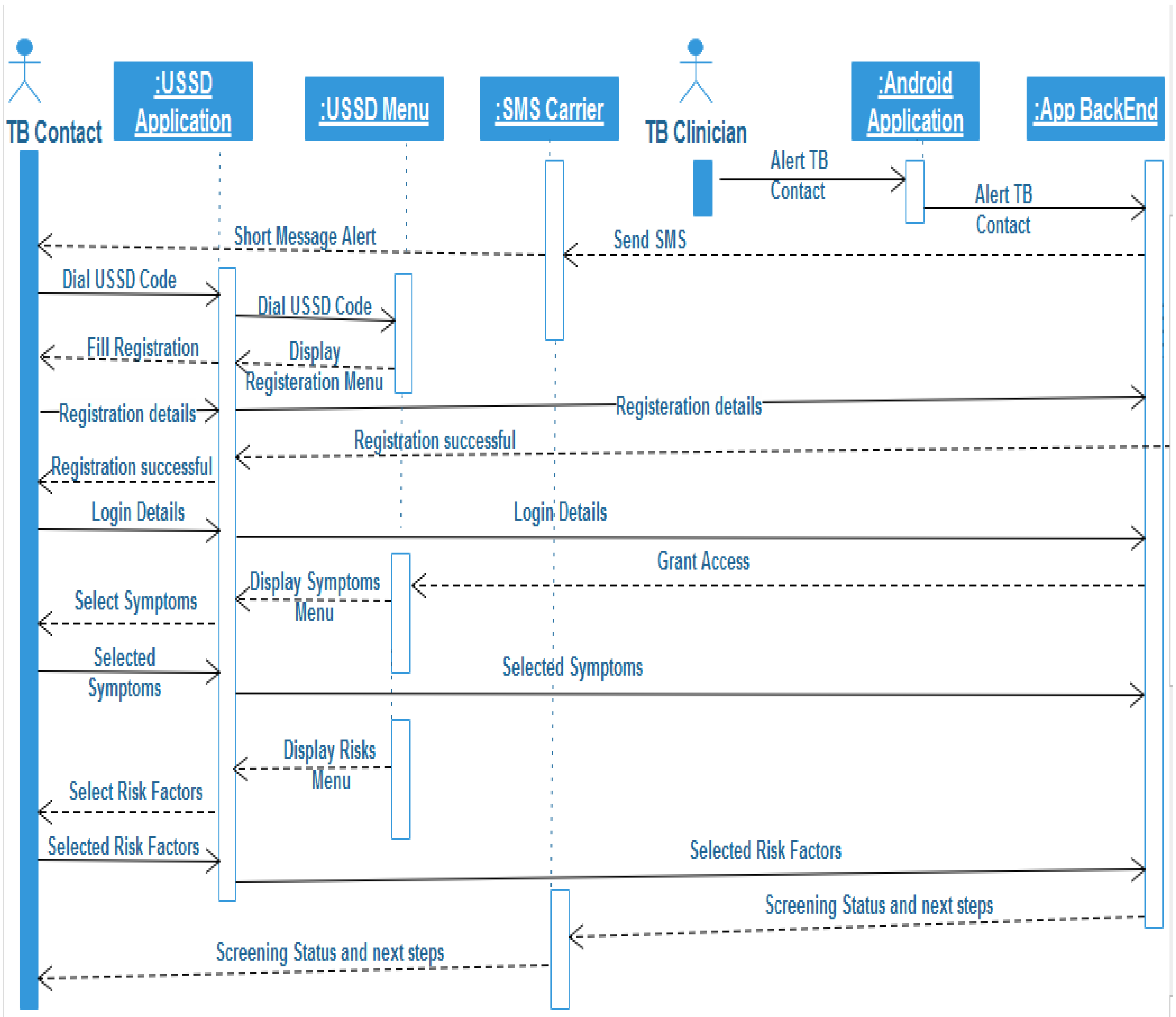


Figure 4. 7 Sequence Diagram

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; 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.

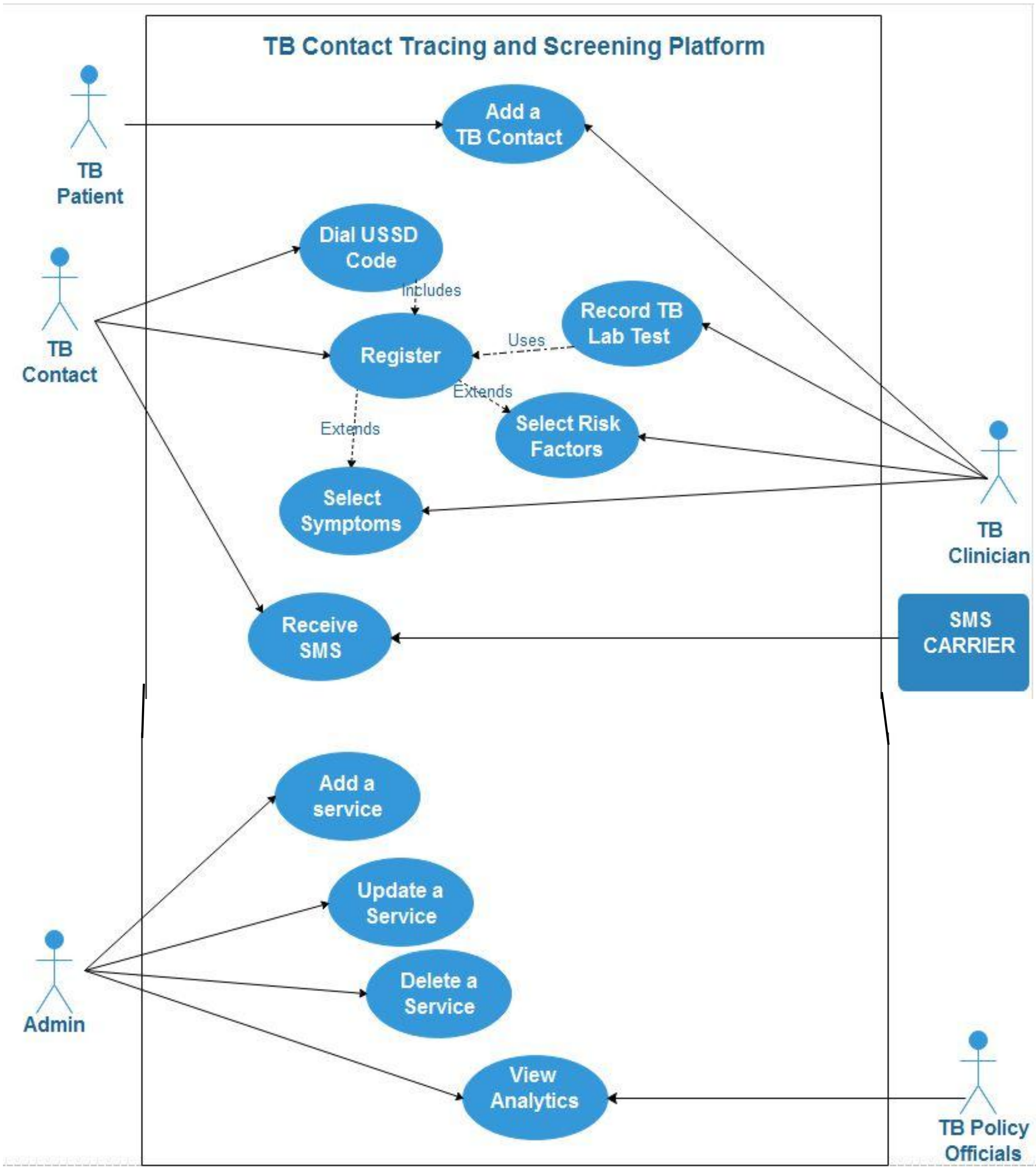


Figure 4. 8 Use Case Diagram

Use Case Description

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

Table 4. 1 Add a TB Contact Use Case

<table>
<tr><td colspan="2">Use Case 1: Add a TB Contact</td></tr>
<tr><td colspan="2">Use Case Description: This use case describes how a TB contact is identified and indexed</td></tr>
<tr><td colspan="2">Primary Actors: TB Patient and TB clinician</td></tr>
<tr><td colspan="2">Pre-conditions: A patient has been tested and confirmed to have TB
The TB clinician is successfully logged into the Android Application</td></tr>
<tr><td colspan="2">Post-condition: TB contact identified, indexed and alerted.</td></tr>
<tr><td colspan="2" align="center">Main Success Scenario</td></tr>
<tr><td>Actor
1. TB Patients lists down his contacts to the TB clinicians
2. TB clinicians inputs the data through an Android application</td><td>System
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</td></tr>
</table>

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. User requirements were merged with the researcher specifications to come up with the system design with desirable functionalities to meet the objectives. The following design diagrams and corresponding information will be used to guide the actual implementation of the system.

4.5.1 Design Class Diagram

Figure 4.9 illustrates the interactions of all classes in the system, their corresponding attributes and methods.

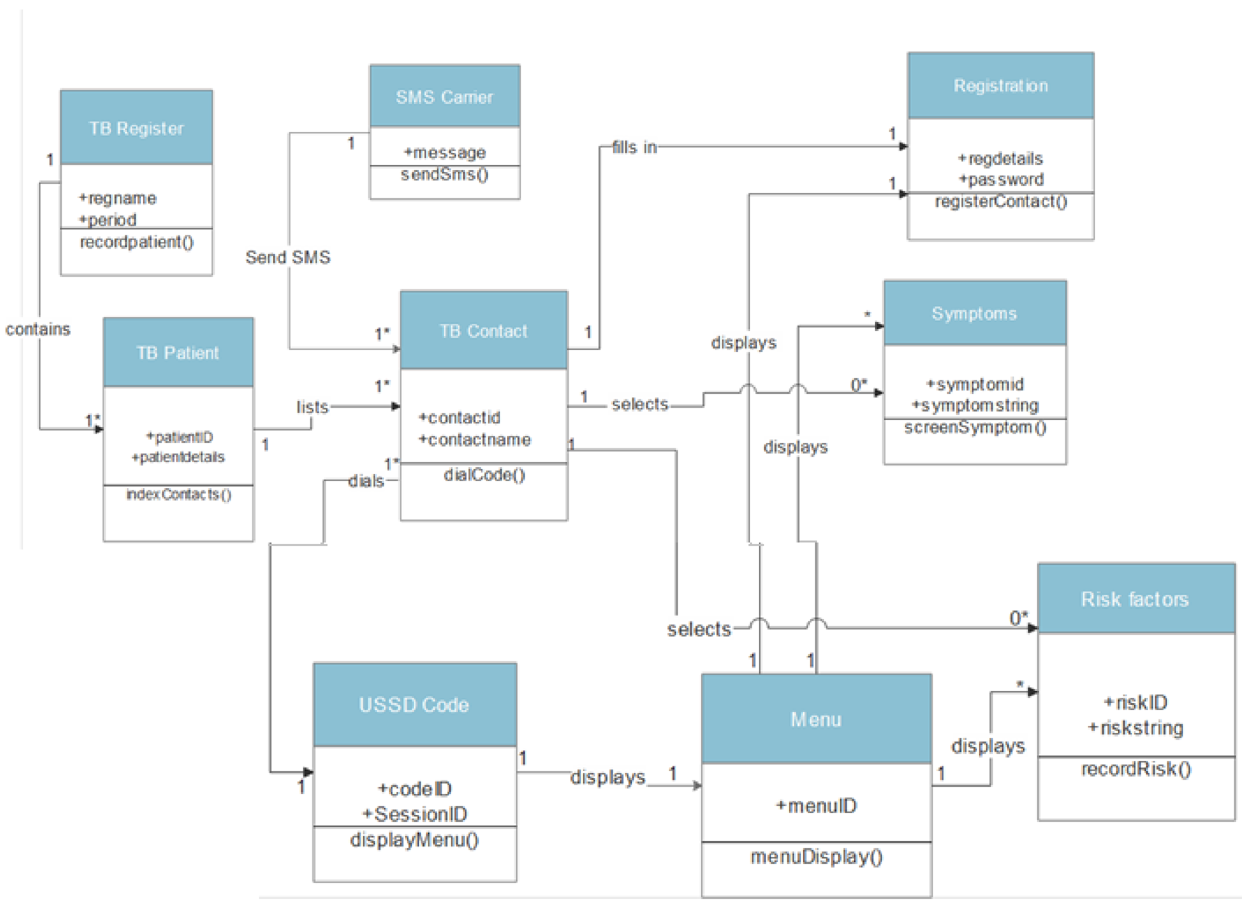


Figure 4. 9 Design Class Diagram

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.

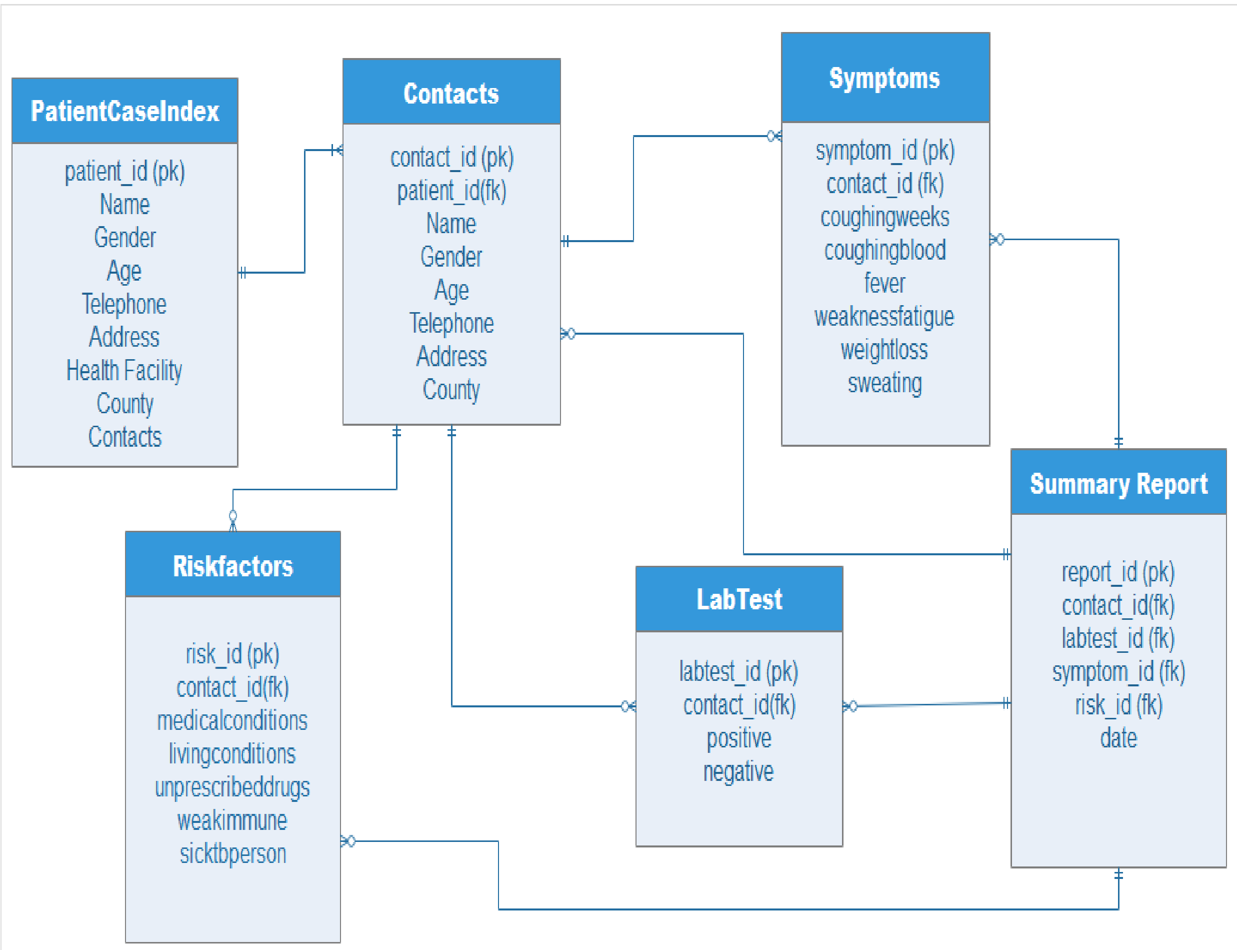


Figure 4. 10 Entity Relationship Diagram

Database Tables Overview

Table 4. 8 Database Tables Overview

Table Name	**Description**
PatientCaseIndex 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
Summary Report table	This table has information of all the responses of symptoms, risks and lab test 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.

Patients Table

Table 4.9 shows the Patients Table that includes the detailed information of confirmed TB patients.

Table 4. 9 Patients Table

Column Name	**Data Type**	**Index**
Patient-id	Varchar(30)	Primary key

Name	Varchar(30)	
Age	Varchar(30)	
Gender	Varchar(30)	
Address	Varchar(30)	
County	Varchar(30)	
Health Facility	Varchar(30)	
Telephone Address	Varchar(30)	
Contacts	Varchar(30)	

Contacts Table

Table 4.10 shows the contacts Table that includes the detailed information of all TB contacts

Table 4. 10 Contacts Table

Column Name	**Data Type**	**Index**
Contact-id	Varchar(30)	Primary key
Patient-id	Varchar(30)	Foreign key
Name	Varchar(30)	
Age	Varchar(30)	
Gender	Varchar(30)	
Address	Varchar(30)	
County	Varchar(30)	
Telephone Address	Varchar(30)	

Symptoms Table

Table 4.11 shows the symptoms Table that includes symptoms of all the TB contacts screened.

Table 4. 11 Symptoms Table

Column Name	**Data Type**	**Index**
symptom-id	Varchar(30)	Primary key
Contact-id	Varchar	Foreign Key
Coughing weeks	Varchar(30)	
Coughing blood	Varchar(30)	
Weight loss	Varchar(30)	
Fever	Varchar(30)	
Sweating	Varchar(30)	
Fatigue	Varchar(30)	

Risks Table

Table 4.12 shows the risks Table that includes the risk factors of all the TB contacts.

Table 4. 12 Risks Table

Column Name	**Data Type**	**Index**
Risk-id	Varchar(30)	Primary key
Contact-id	Varchar(30)	Foreign key
Sick TB person	Varchar(30)	
Living conditions	Varchar(30)	
Weak immune	Varchar(30)	

Unprescribed drugs	Varchar(30)	
Medical conditions	Varchar(30)	

LabTest Table

Table 4.13 shows the LabTest Table that includes the results of all the TB contacts who have undergone a lab test.

Table 4. 13 LabTest Table

Column Name	**Data Type**	**Index**
LabTest-id	Varchar(30)	Primary key
Contact-id	Varchar(30)	Foreign Key
Positive	Varchar(30)	
Negative	Varchar(30)	

Summary Report Table

Table 4.14 shows the Summary Report Table that includes the report of the TB status of the contacts.

Table 4. 14 Summary Report Table

Column Name	**Data Type**	**Index**
report-id	Varchar(30)	Primary key
Contact-id	Varchar(30)	Foreign Key
Symptoms-id	Varchar(30)	Foreign Key
Risk-id	Varchar(30)	Foreign Key
LabTest-id	Varchar(30)	Foreign Key

Date	Varchar(30)	

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. The wireframe diagrams can be found at Appendix C. Figure C.2 shows how a TB contact is able to log into the USSD application. After the user is logged in is able to view the USSD menu as shown in figure C.3. The user can select symptoms as shown in figure C.4 and complete the process of screening by selecting risk factors as shown in figure C.5

The system also has an Android application, which allows TB clinicians to log in, index, and record lab results of TB contacts. Figure C.9 shows the menu of the application. Figure C.10 shows the flow of the events as the TB clinician adds contacts. The TB clinicians as shown in figure C.11 record the Labtest of the TB contacts. The system will also have a website backend where reports and data analytics will be done. The website will have a registration and login for the administrator and TB policy officers as shown by Figure C.12. Once logged in the administrator will be able to view the reports on the symptoms, risk factors and lab results of the TB contacts as shown in figure C.13.

Chapter 5: System Development, Implementation 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. The testing section of this chapter focuses on usability testing and functional testing to verify if the application attains the objectives of the proposed solution.

5.2 Implementation Environment

The application comprised 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. The TB clinician's mobile application was developed on the Android platform. The web application was developed on a PHP framework, which is Laravel 5.2 and hosted on an 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 in USSD application, Android application and a web backend known as *TiBa*. The website backend enabled the administrator to manage the application and view reports, which is useful for data analytics.

5.3.1 TiBa USSD Application

The TiBa 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 a screen shot of the main Menus.

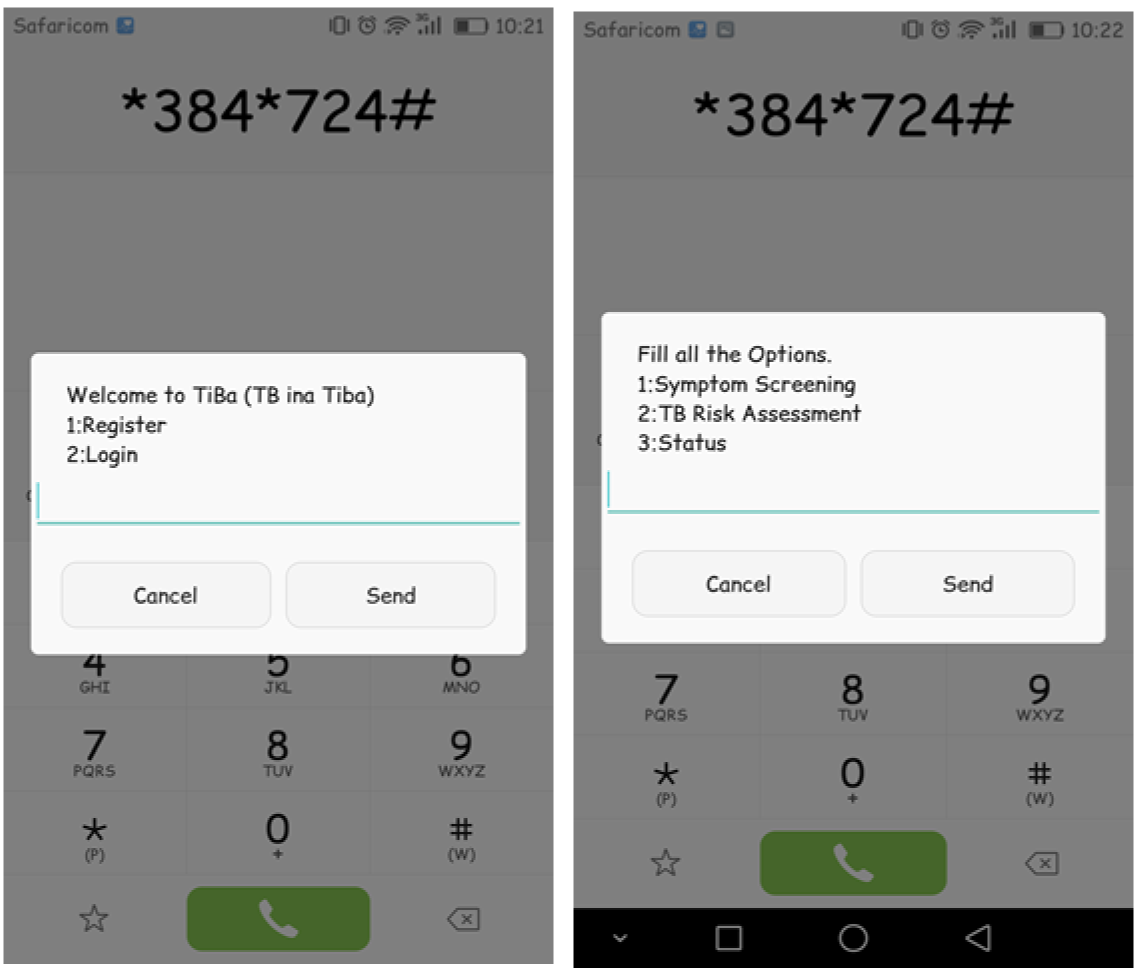


Figure 5. 1 Screen Shots of the Main Menus of USSD Application.

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.

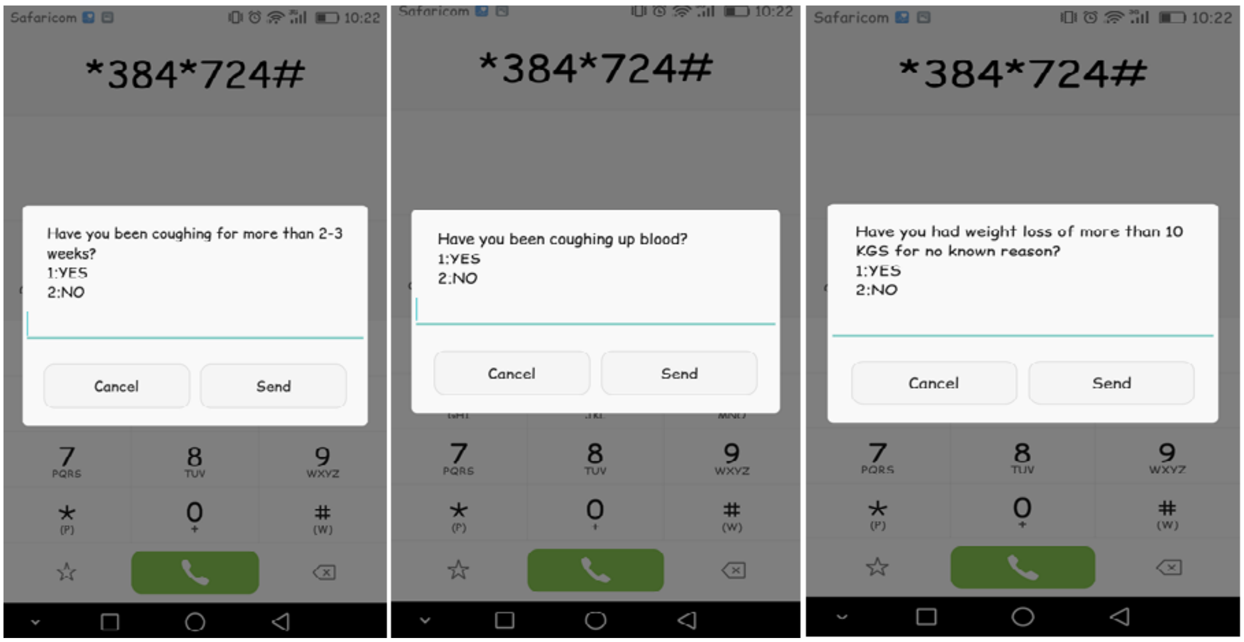


Figure 5. 2 Sample screen shots of selecting symptoms

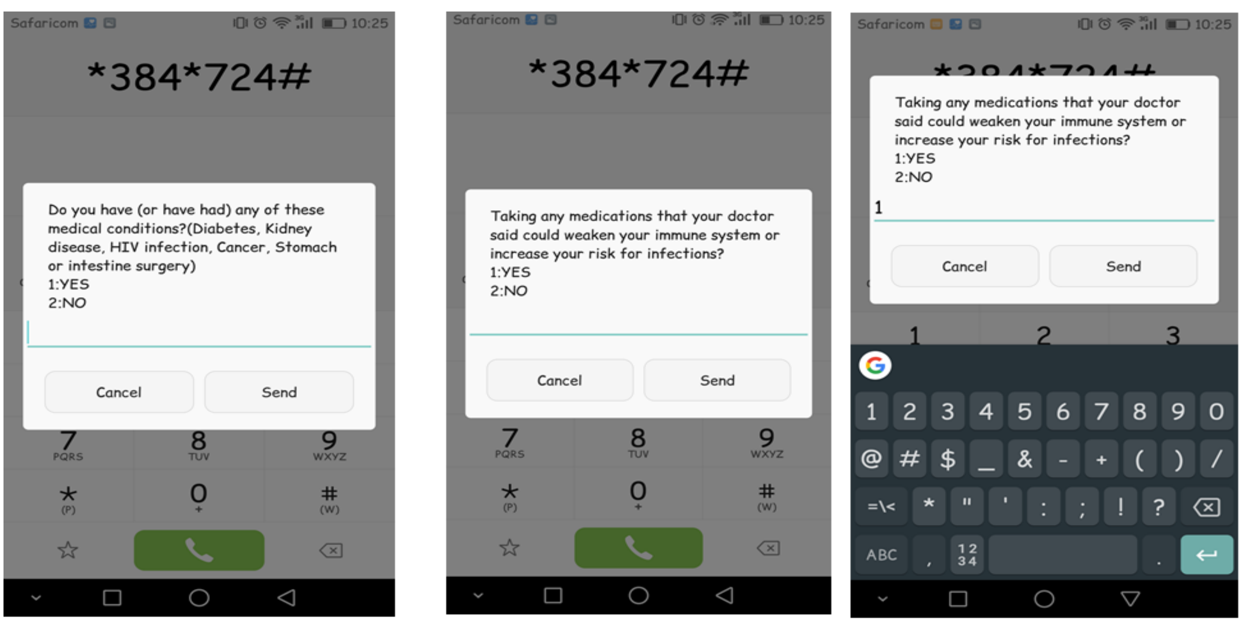


Figure 5. 3 Sample screen shots of selecting risk factors

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

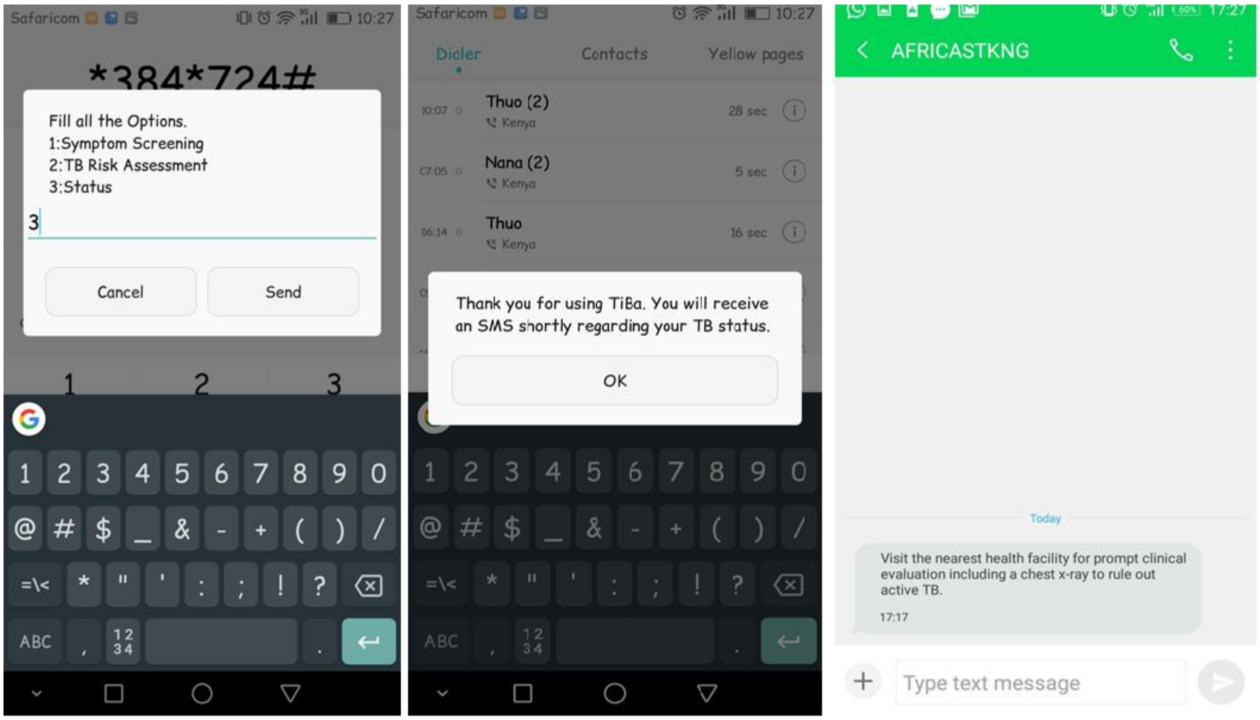


Figure 5. 4 Screenshots of checking status notification

5.3.2 TiBa Android Application

The TiBa 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 back-end 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.

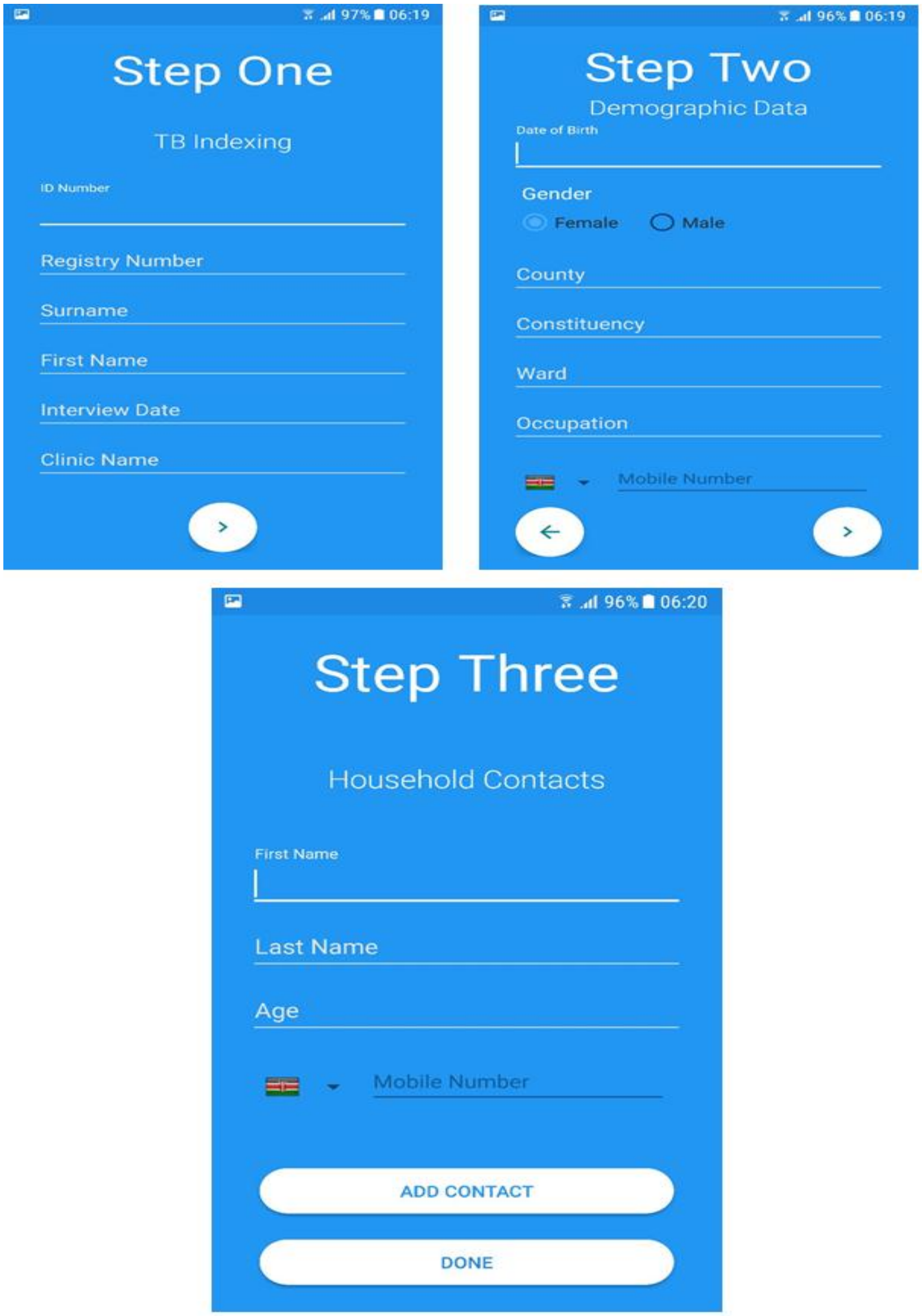


Figure 5. 5 Screenshot of TB patient indexing

5.3.2 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.

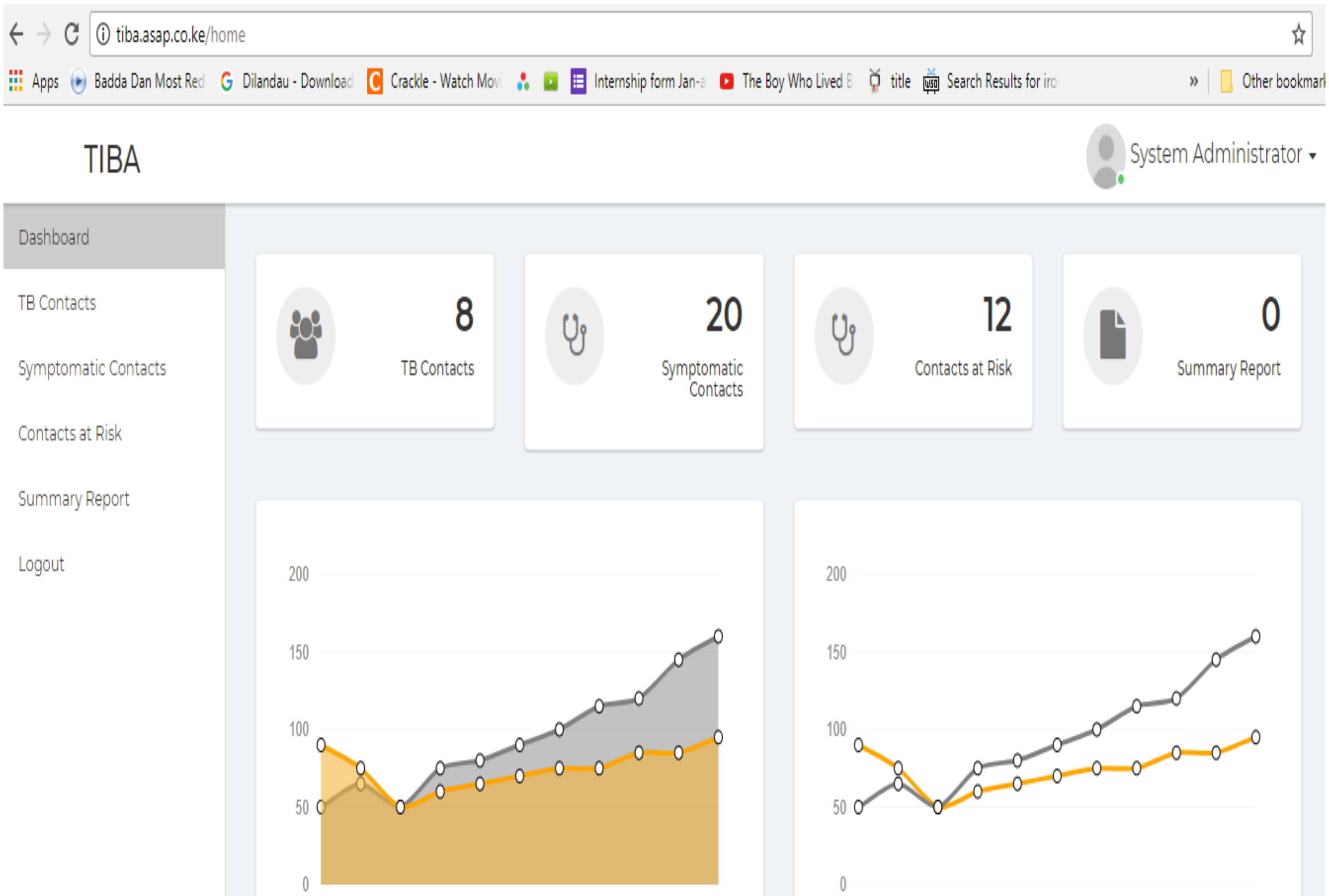


Figure 5. 6 Screenshot of Web application Dashboard

5.4 System Testing

This section describes tests that were performed 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 behaviour 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 5.6: Record TB Lab Test Results

Table 5.4 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 behaviour 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. The results were as follows; 98% of the potential users indicated that the application was easy to learn and use. Figure 5.7 shows a summary of the results.

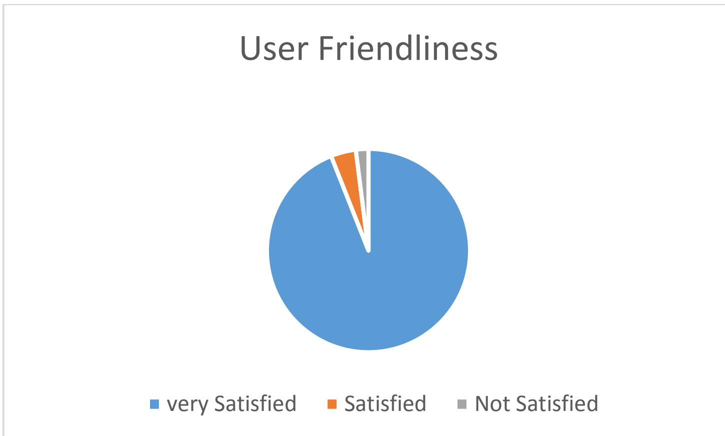


Figure 5. 7 User Friendliness Testing

ii. Functionality

Potential users of the application tested the system functionality against the user specifications. 95% of them indicated that they were very satisfied with the application’s functionality meaning that the developer achieved most of the user functionality and requirements specification, 5% indicated that they were not satisfied with the application’s functionality meaning that some of the user specifications were not entirely meet. This result was used to refine the system until an acceptable application was developed. A summary of the results is shown in Figure 5.8.

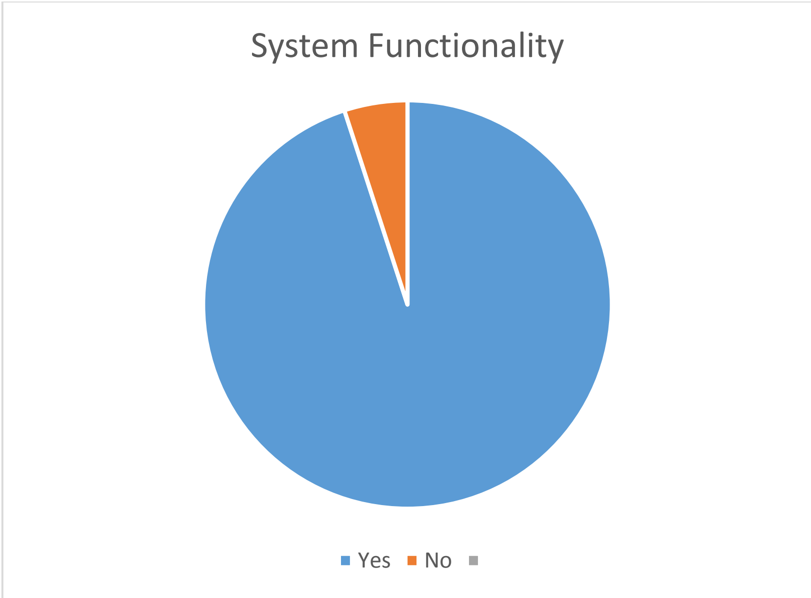


Figure 5. 8 System Functionality Acceptance Testing

iii) Acceptability

To measure if the application was great success user acceptance was tested. 96% of the potential users gladly accepted the application for use in TB contact tracing and screening. 4 % did not accept the application meaning that there were some aspects about it that they wish would be different. Since majority of the users gladly accepted the application this test was a great success. Figure 5.3 provides a summary of these results.

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 respondents indicated that the application was acceptable while the remaining percentage indicated that the application was not pleasing to the eyes. A summary of the results can be viewed in Figure 5.4.

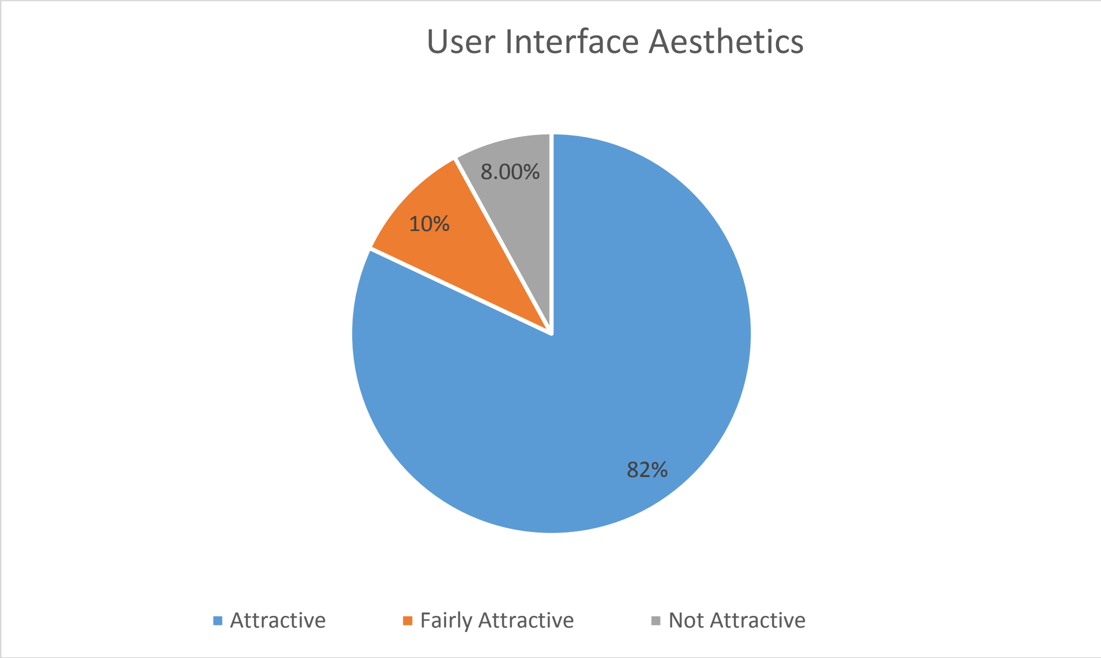


Figure 5. 10 User Interface Aesthetics

5.4.3 Compatibility Testing

Compatibility testing was done to ensure that both the web application and Android application were compatible with the existing platforms. Mobile application was tested on the existing Android versions while the web application was tested on the all the major web browsers.

Android Platform Testing

The 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

The 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 5.5 shows what the users thought of the implementation and if the system solved the problem.

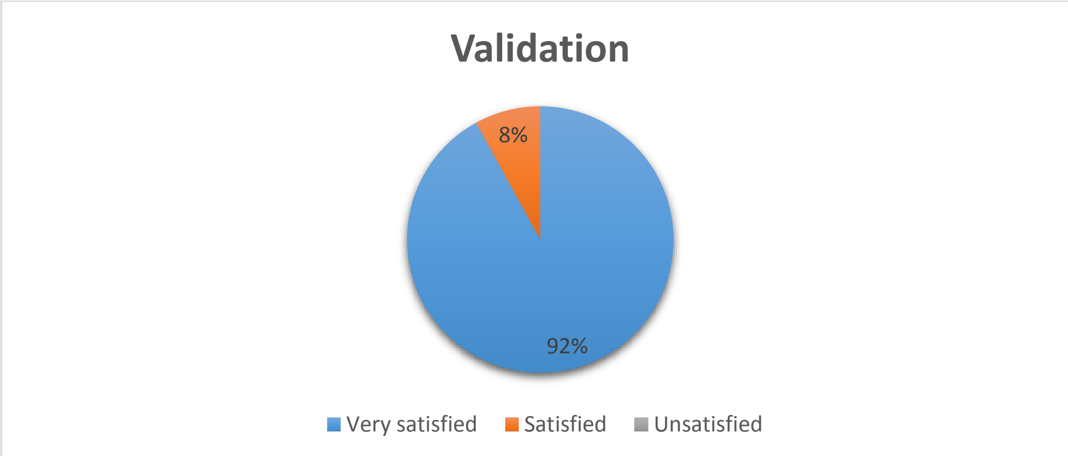


Figure 5. 11 Validation of System

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 done to ensure user requirements were met, Compatibility Testing; was done to test Android and web based application to Android platform and web browsers respectively , User Testing; was done to test User Friendliness, Application Functionality and User Acceptance of the prototype.

Chapter 6: Conclusions and Recommendations

6.1 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.

6.2 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.

The successful integration of these novel methodologies will require community involvement, capacity building and ongoing support at every level. The outcome will not only be the systematic collection, analysis, and interpretation of contact tracing and screening data in high-burden communities to assess transmission but the prioritization of contacts who are candidates for treatment of LTBI which will break the cycle of transmission. Ultimately, the measure of success will be a clear and sustained decline in TB incidence in Kenya.

6.3 Future works

The research findings for this dissertation are not final and hence there exists more room for improvement. Key areas include the development and validation of a network-informed Contact tracing and screening tool, development of a geographical information system for contact tracing, explore utility, feasibility, integration of the system with existing systems used in hospitals, evaluation and development of Android based application with abilities of image recognition TB chest X-ray and lastly explore the extent and use of Contact tracing and screening data collected.

References

Armbuster , B., & Brandeu, M. L. (2007). Optimal Mix Screening amd Contact tracing for endemic diseases. *Math Biosciences*, 209(2), 386-402.

Ayisi, J. G., Van't Hoog, A. H., Agaya, J. A., Muchembere, W., Nyamthimba, P. O., Muhenje, O., & Marston, B. J. (2011). Care Seeking and Attitudes towards Treatment Compliance by Newly Enrolled Tuberculosis Patients in the District Treatment Programme in Rural Western Kenya, A Qualitative Study. *BMC Public Health*, 11, 500-515.

Bailey , W. C., Gerald , L. B., & Kimerling, M. E. (2002). Predictive model to identify positive tuberculosis skin test results during contact investigations. *JAMA*, 287, 996-1002.

Behr , M. A., Hopewell , P. C., Paz , E. A., Kawamura, L. M., Schecter, G. F., & Small, P. M. (1998). Predictive value of contact investigation for identifying recent transmission of Mycobacterium tuberculosis. *American Journal of Respiratory Critical Care Medicine.*, 158 (2), 465-469.

Benbasat, I., & Barki, H. (2007). Quo vadis, TAM? *Journal of the Association for Information Systems*, 8(4), 211-218.

Billingsley, K., Smith , N. H., Shirley, R., & Keiser, P. (2011). A quality assessment tool for tuberculosis control. *Tuberculosis (Edinburgh, Scotland)*, 4-11.

Blaya , J. A., Fraser , H. S., & Holt , B. (2010). E-health technologies show promise in developing countries. *Health Aff*, 29:244–251.

Caldeira, Zelina, M. R., & Clemax , C. (2004). Tuberculosis contact tracing among children and adolescents,Rio de Janeiro. *Rev Saude Publica.* , 339-345.

Calderwood , M. S., Platt, R., & Hou , X. (2010). Real-time surveillance for tuberculosis using electronic health record data from an ambulatory practice in eastern Massachusetts. *Public Health Rep*, 125:843–850.

Caminero, J. A. (2008). Likelihood of generating MDR-TB and XDR-TB under adequate National Tuberculosis Control programed implementation. *International Journal for Tuberculosis and Lung Diseases*, 12(8),869-877.

Chapman, A. L., Darton, T. C., & Foster, R. A. (2013). Managing andmonitoring tuberculosis using Web-based tools in combination with traditionalapproaches. . *Clinical Epidemiology*, 5: 465–473.

Cook , V. J., Sun , S. J., Tapia , J., Muth , S. Q., Arguello, D. F., & Lewis , B. L. (2007). Transmission network analysis in Tuberculosis contact investigations. 1. *J Infect Dis*, 96:1517-27.

Crawford , J. T. (2003). Genotyping in contact investigations: a CDC perspective. *Int J Tuberc Lung Dis.*, 7:S453–S457.

Davis, F. D., Bagozzi, P. R., & Warshaw , P. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science*, 35, 982-1003.

Denkinger, C. M., Grenier, J., Stratis, A. K., Akkihal, , A., Pant-Pai, N., & Pai, M. (2013). Mobile health to improve tuberculosis care and control: A call worth making. *International Journal of Tuberculosis and Lung Disease*, 17(6), 719– 727.

Dye , C., Maher, D., Weil, D., Espinal, M., & Raviglione, M. (2006). Targets for global tuberculosis control. *International Journal for Tuberculosis Lung Disorders*, 10 (4) ,460-462.

Erkens , C. G., Kamphorst , M., Abubakar, I., Bothamley , G. H., Chemtob, D., Haas , W., . . . Lange , C. (2010). Tuberculosis contact investigation in low prevalence countries: A European consensus. *European Respiratory Journal*, 36 (4) ,925-949.

Fishbein, M., & Ajzen, I. (1975). *Belief, Attitude, Intention and Behavior: An Introductionto Theory and Research.* MA, USA: Addison-Wesley.

Gardy , J., Johnston, J. C., & Ho Sui , S. J. (2011). Whole genome sequencing and social network analysis of a tuberculosis outbreak. *N Engl J Med*, 364:730-739.

Hanson, R. L., Gannon, M. J., Khamo , N., Sodhi , M., Orr, A. M., & Stubbings, J. (2013). Improvement in safety monitoring of biologic response modifiers after the implementation of clinical care guidelines by a specialty. *J Manag Care Pharm*, 19:49–67.

Heller , R. F., Gemmell, I., Edwards , R., Buchani, I., Awasthi , S., & Volmink , J. A. (2006). Prioritising between direct observation of therapy and case-finding interventions for tuberculosis: use of population impact measures. *BMC Med*, 4:35.

Kliner, M., Knight, A., Elston, J., & Humphreys, C. (2013). Development and testing of models of tuberculosis contact tracing in rural southern Africa. *Public Health Action*, 3(4), 299-300.

Klovdahl , A. S. (2015). Social Networks and the spread of infectious the AIDS example. *Soc Sci Med*.

Kwon, H. S., & Chidambaram, L. (2000). A Test of the Technology Acceptance Model; the Case of Celluar Telephone Adoption. Hawaii International Conference on System Sciences proceedings. *Hawaii International Conference on System Sciences proceedings*, (pp. pp. 1-10).

Lambert , M. L., & Van der Stuyft, P. (2005). Delays to tuberculosis treatment: shall we continue to blame the victim? *Trop Med International Health*, 10 (10) ,945-946.

Lau , F., Price , M., Boyd, J., Partridge, C., Bell , H., & Rawor , R. (2012). Impact of electronic medical record on physician practice in office settings: a systematic review. *BMC Med Inform Decis Mak*, 12:10.

Lee, Y., Koza, K. A., & Larsen, K. R. (2003). The Technology Acceptance Model: Past, Present, and Future. *Communications of AIS*, 12, 752-780.

Lemos, A. C., Matos, E. D., Pedral-Sampaio , D. B., & Netto, E. M. (2004). Risk of tuberculosis among household contacts in Salvado, Bahia. . *Brazil Journal of Infectious Diseases*, 8,424-430.

Leung, C. C., Rieder , H. L., Lange , C., & Yew , W. W. (2011). Treatment of latent infection with Mycobacterium tuberculosis: update 2010. *European Respiratory Journal*, 37 (3) ,690-711.

Liker, J. K., & Sindi, A. A. (1997). User Acceptance of Expert Systems: A test of the Theory of Reasoned Action. . *Journal of Engineering and Technology Management*, 14, 147-173.

Lobato, M. N., Wang, Y. C., Becerra , J. E., Simone, P. M., & Castro . (2006). Improved program activities are associated with decreasing tuberculosis incidence in the United States. *Public Health Reports Journal*, 121 (2) ,108-115.

Lobue , P. A., Lademarco , M. F., & Castro , K. (2008). *The Epidemiology, Prevention, and Control of Tuberculosis in the United States. Fishman's Pulmonary Diseases and Disorders. 4th ed.* New York: The McGraw-Hill Companies Inc.

McElroy , P. D., Rothenberg, R. B., Varghese, R., & Woodruff, R. (2016). A network-informed approach to investigating a tuberculosis outbreak: implications for enhancing contact investigations. . *Int J Tuberc Lung Dis.*, S486-S93.

Moonan , P. K., Bayona , M., Quitugua, T. N., Oppong , J., & Dunbar , D. (2014). Using GIS technology to identify areas of tuberculosis transmission and incidence. *Int J Health Geogr*, 3:23.

Morrison, J., Pai , M., & Hopewell , P. C. (2008). Tuberculosis and latent tuberculosis infection in close contacts of people with pulmonary tuberculosis in low-income and middle-income countries: a systematic review and meta-analysis . *Lancet Infection Disorders*, 8 (6) ,359-368.

Pagani, M. (2004). Determinants of Adoption of Third Generation Mobile Multimedia Services. *Journal of Interactive Marketing,*, 18(3), 46-59.

Pederson, E. (2003). Adoption of Mobile Internet Services: An Exploratory Study of Mobile Commerce Early Adopters. *Journal of Organizational Computing and Electronic Commerce*, 15(3), 203-222.

Pederson, E., & Thorbjornsen, H. (2002). *Adoption of Mobile Services. Model Development and Cross-Service Study.* SNF Report.

Shabbeer, A., Ozcaglar , C., Yener, B., & Bennett , K. P. (2012). Web tools for molecular epidemiology of tuberculosis. *Infect Genet Evol*, 12:767–782.

Simba , D. O. (2004). Application of ICT in strengthening health information systems in developing countries in the wake of globalisation. *Afr Health Sci*, 4:194–199.

Sreeramareddy, C. T., Panduru , K. V., Menten, J., & Van den , E. N. (2009). Time delays in diagnosis of pulmonary tuberculosis: a systematic review of literature. *BMC Infectious Disorders*, 9,91.

Tardin, A., Dominice, D. M., & Janssens, J. P. (2009). Tuberculosis cluster in an immigrant community: case identification issues and a transcultural perspective. *Trop Med Int Health*, 14:995–1002.

Tata Teleservices Ltd. (2007). *End to end USSD system implementation in GSM-CDMA.* Retrieved from https://www.cdg.org/resources/files/white_papers/End%20to%20End%20USSD%0Implementation.pdf

Vishnoi , A., Srivastava, A., Roy, R., & Bhattacharya , A. (2008). MGDD: Mycobacterium tuberculosis genome divergence database. *BMC Genomics.*, 9:373.

Volkmann, T., Okelloh, D., Agaya, J., & Cain, K. K. (2016). Pilot implementation of a contact tracing intervention for tuberculosis case detection in Kisumu County, Kenya. *Public Health Action*, 6(4), 217–219.

Weniger, T., Krawczyk, J., Supply, P., Harmsen , D., & Nieman, S. (2012). Online tools for polyphasic analysis of Mycobacterium tuberculosis complex genotyping data: now and next. *Infect Genet Evol*, 12:748–754.

World Health Organization. (2010). *Global tuberculosis control.* Geneva: World Health Organization.

World Health Organization. (2015). *Global tuberculosis Report 2015.* Geneva: World Health Organization.

Yoonhee , P. H., Martha , A., Ryan , L., Rebecca , S. G., Tumelo , O. M., Scarlett , L. B., . . . Carrie , L. K. (2016). Evaluation of a Mobile Health Approach to Tuberculosis Contact Tracing in Botswana. *Journal of Health Communication*, 21:10, 1115-1121.

Appendices

Appendix A: 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 B: Screen Shots

USSD Screen Shots

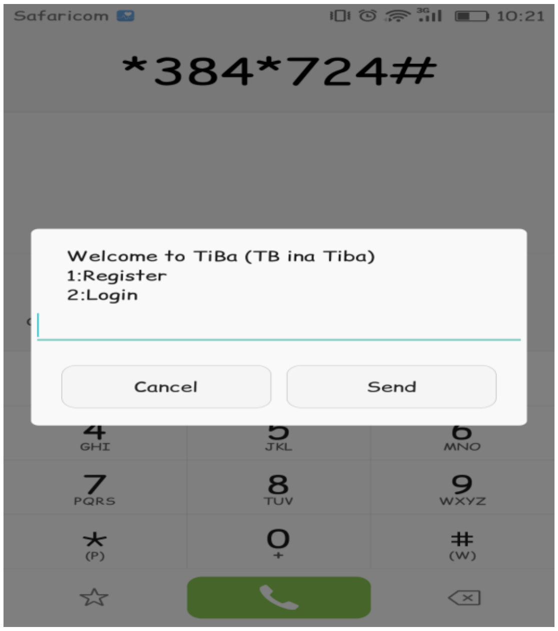


Figure B. 1 USSD Login Menu Screen Shot

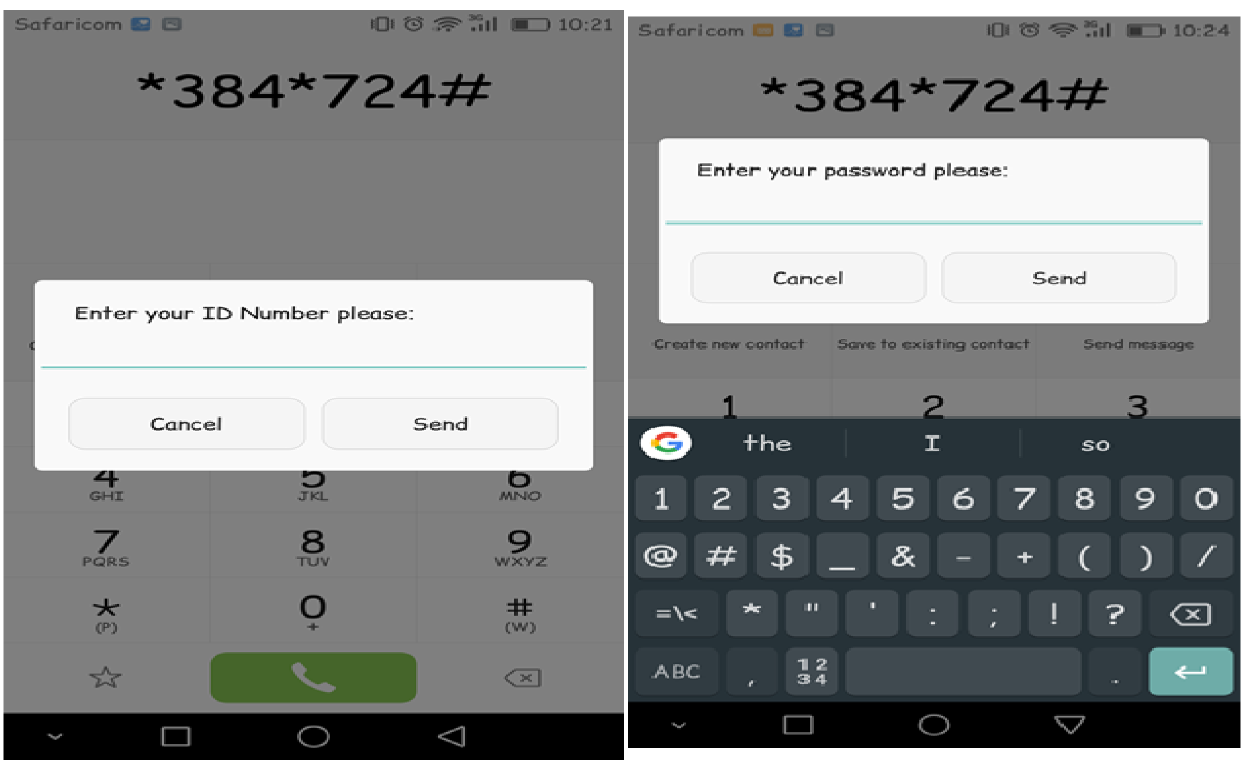


Figure B. 2 USSD Login Details Screenshot

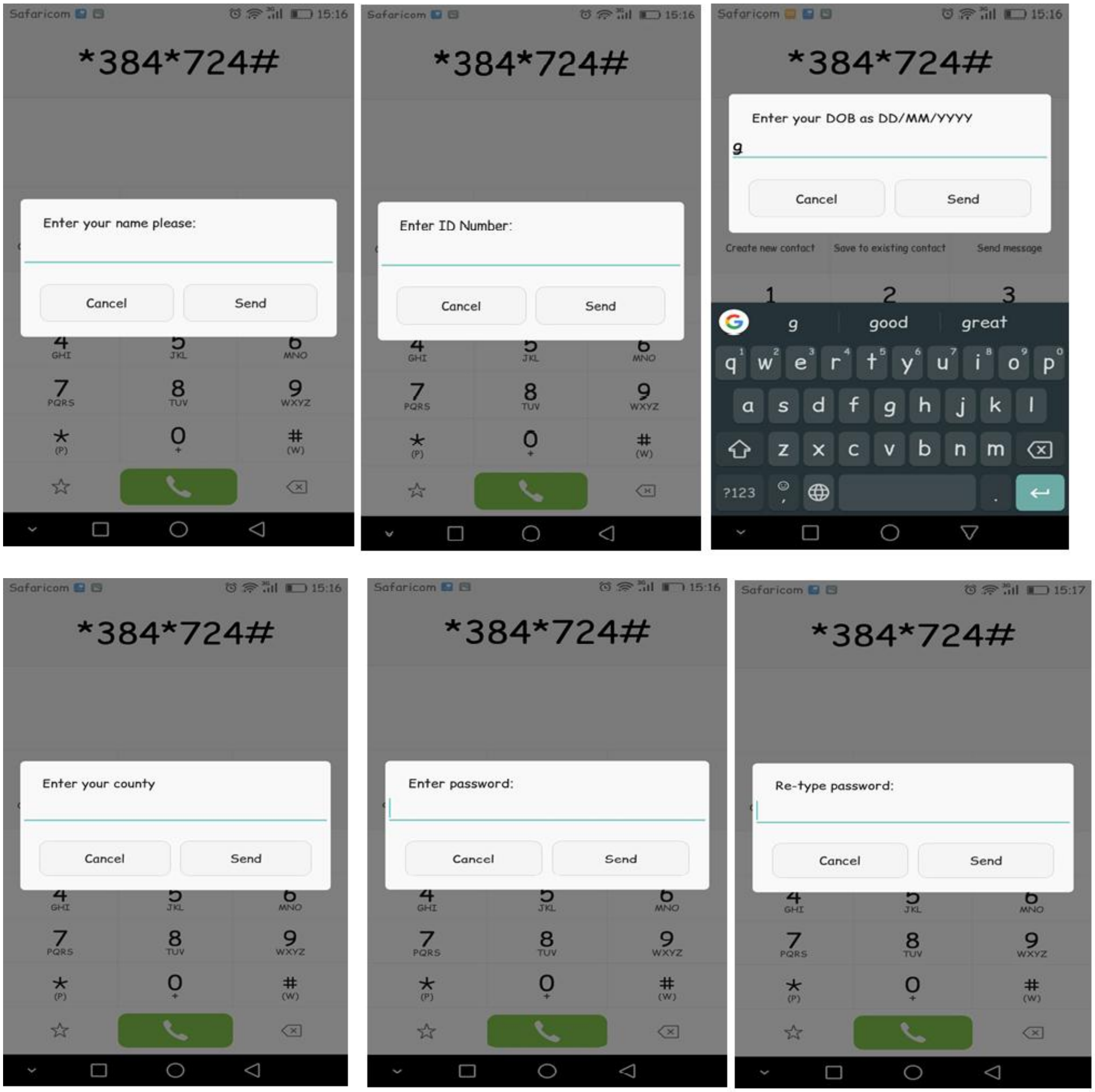


Figure B. 3 USSD Registration Details ScreenShot

Android ScreenShots

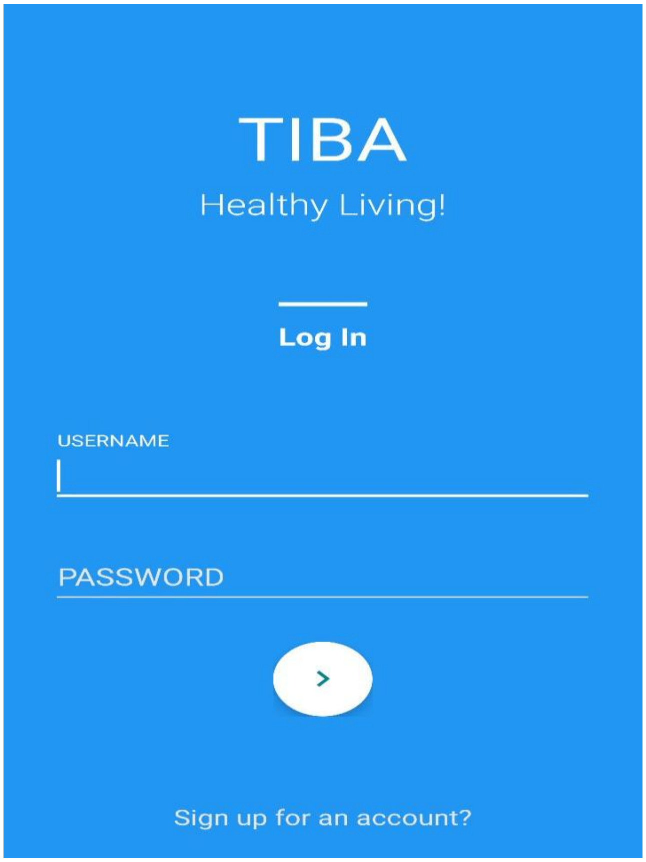


Figure B. 4 Android Login Screen Shot

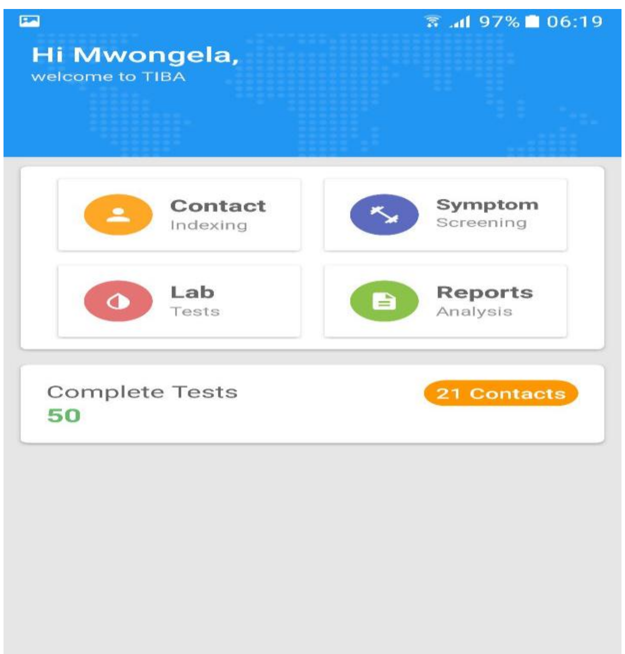


Figure B. 5 Android Main Menu Screen Shot

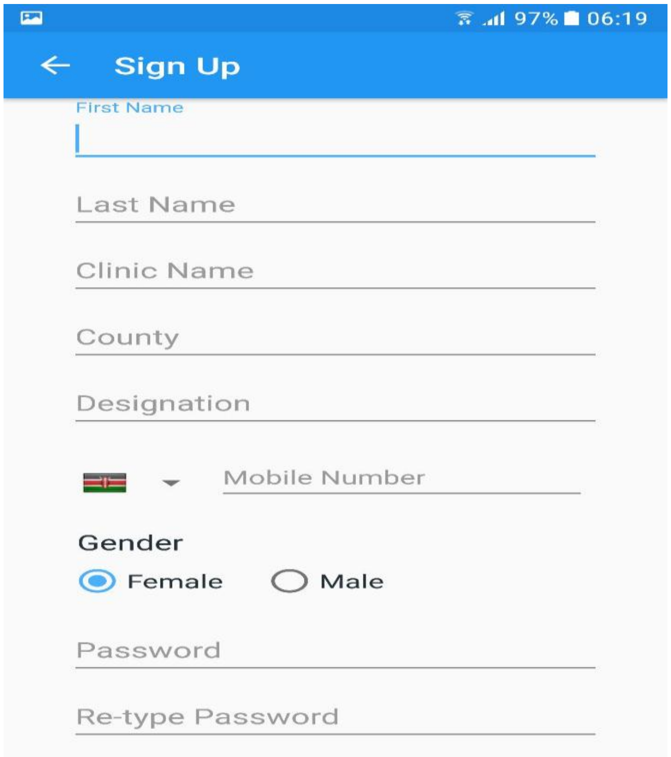


Figure B. 6 Sign-Up Sheet

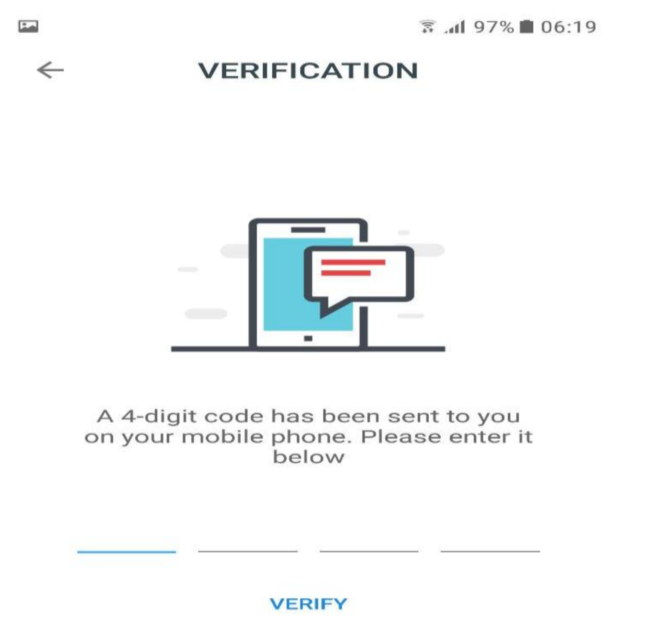


Figure B. 7 Verification Screenshot

Web application screen shots

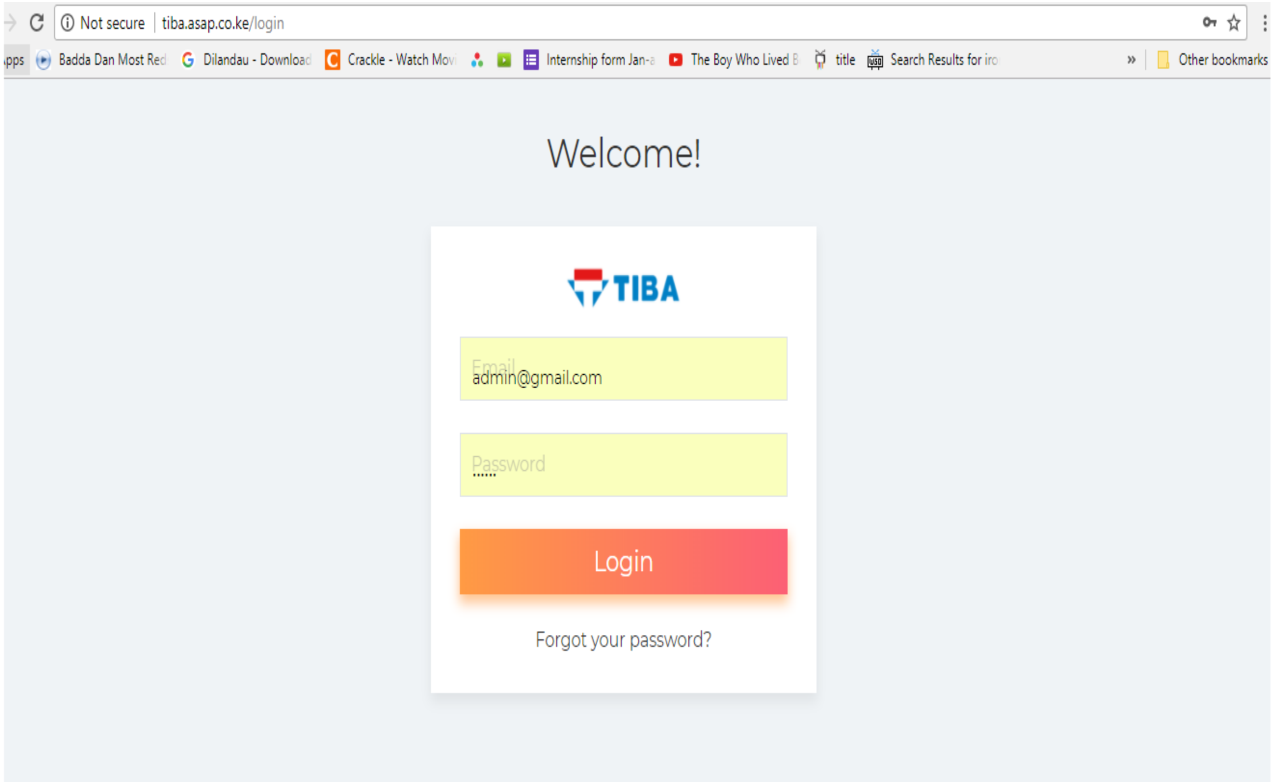


Figure B. 8 Administrator Login in the web application

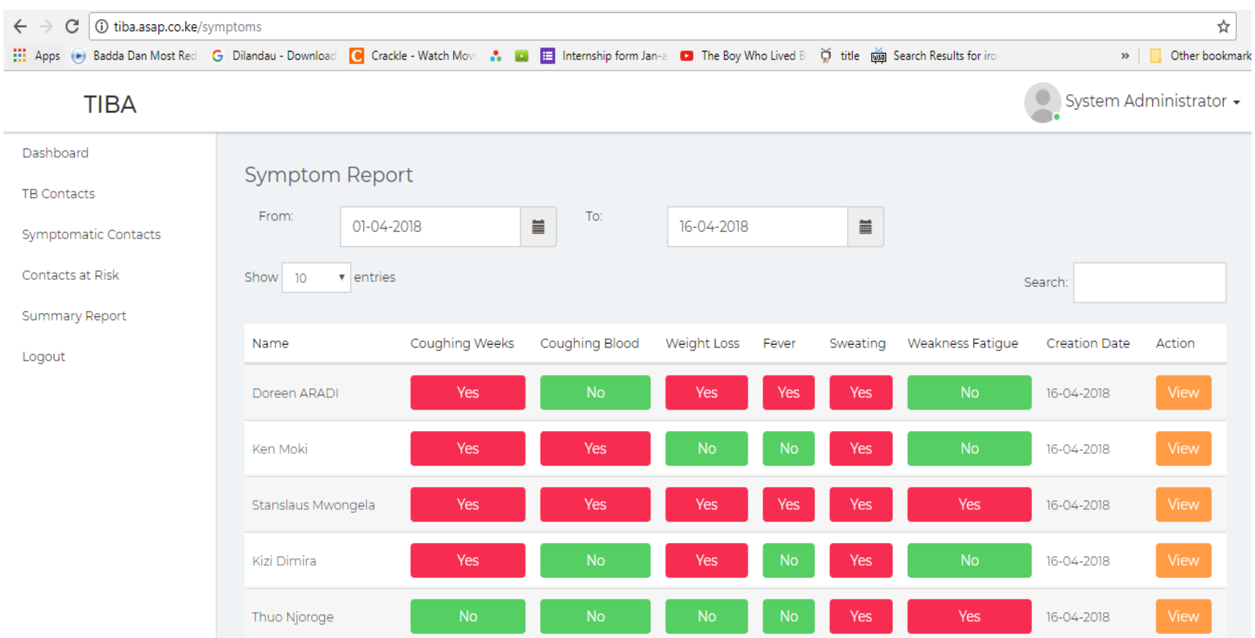


Figure B. 9 Symptoms Report Screenshot

Appendix C: Wireframes

USSD Application Wire frames

Figure C. 1 Welcome Page

Figure C. 2 Login Page

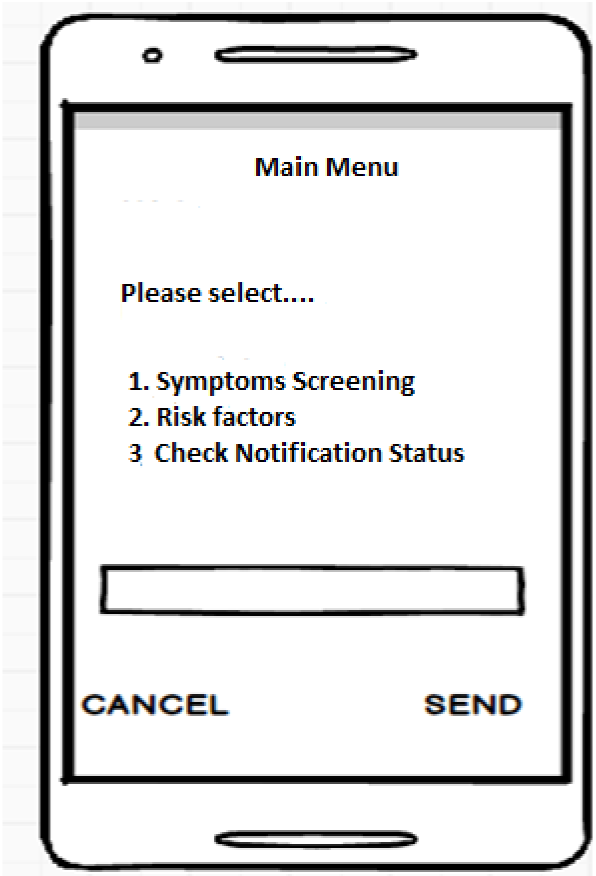
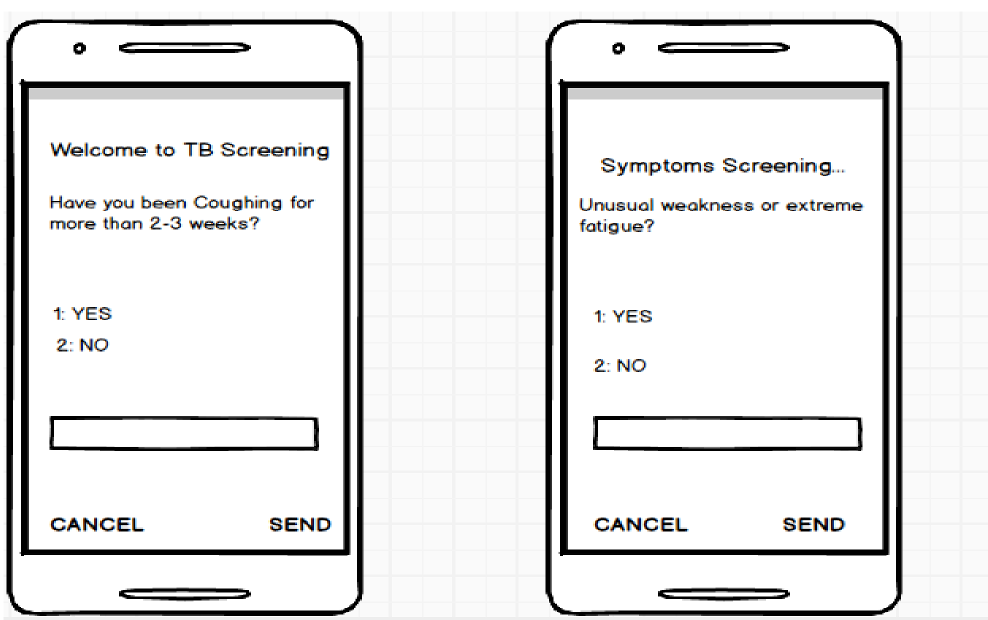


Figure C. 3 Main Menu Wireframes



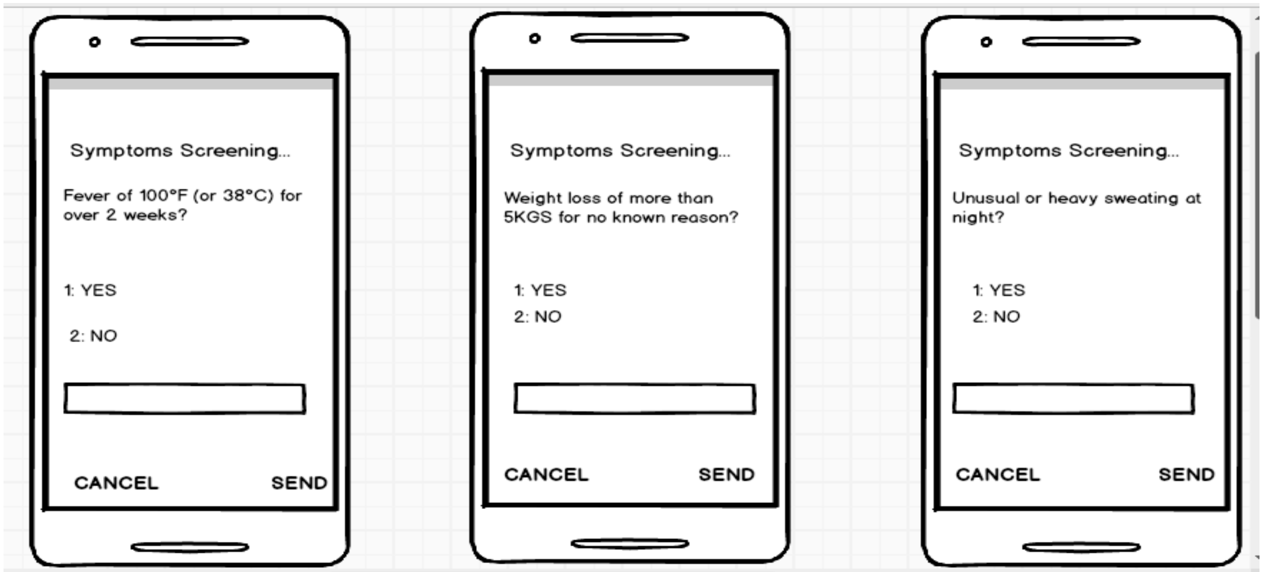
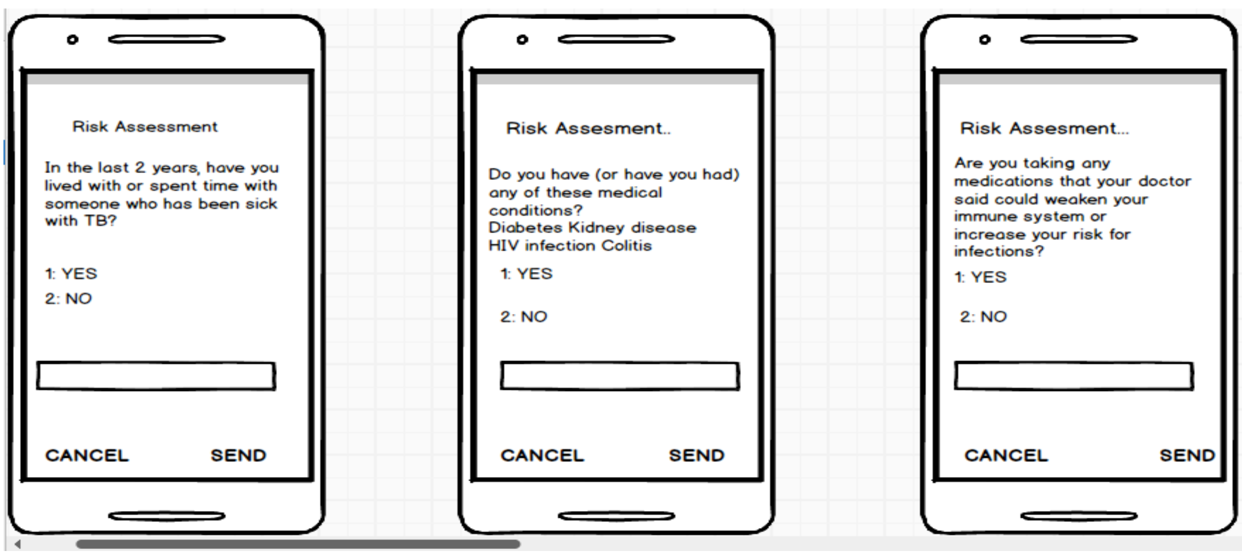


Figure C. 4 Symptoms screening wireframes



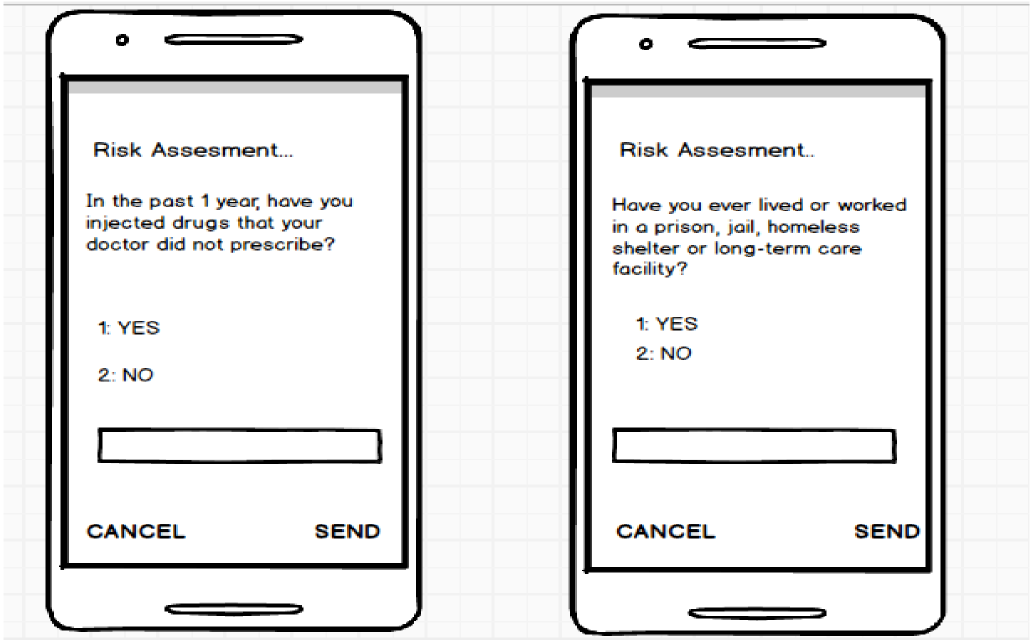
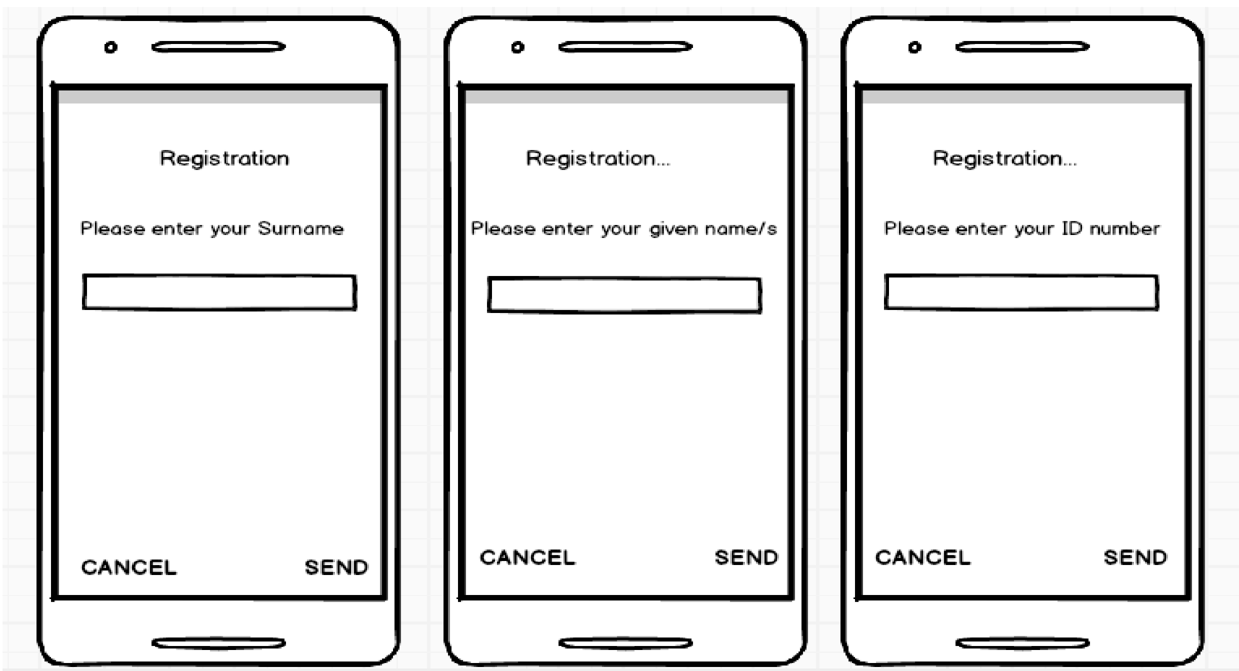


Figure C. 5 Risk factors wire frame



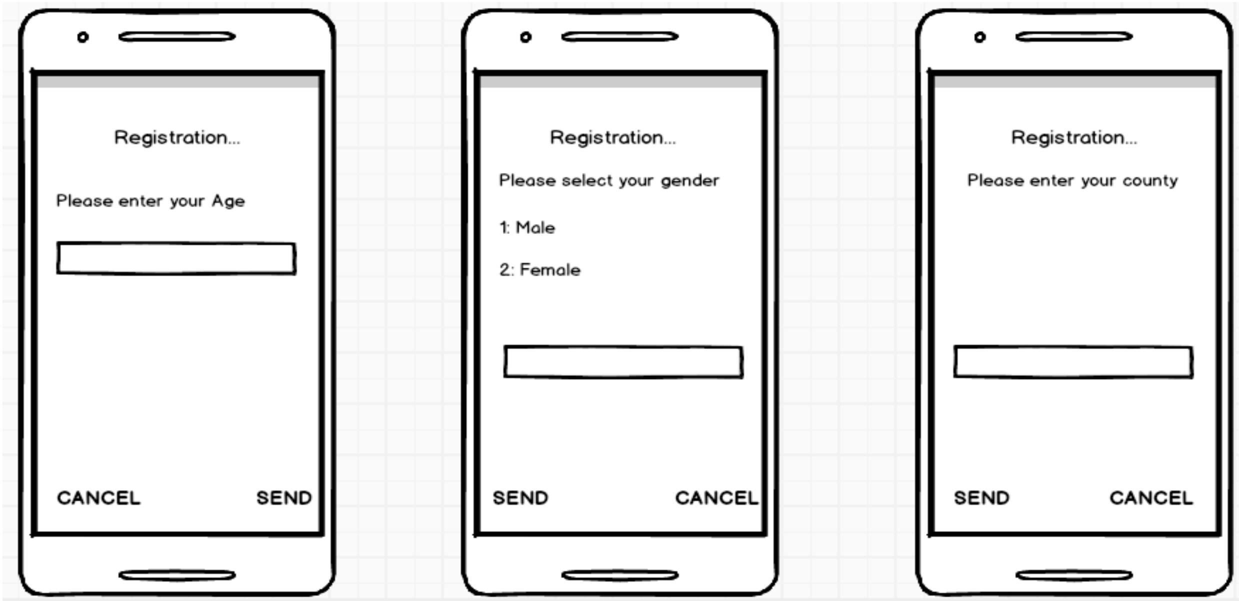


Figure C. 6 Registration Wireframes

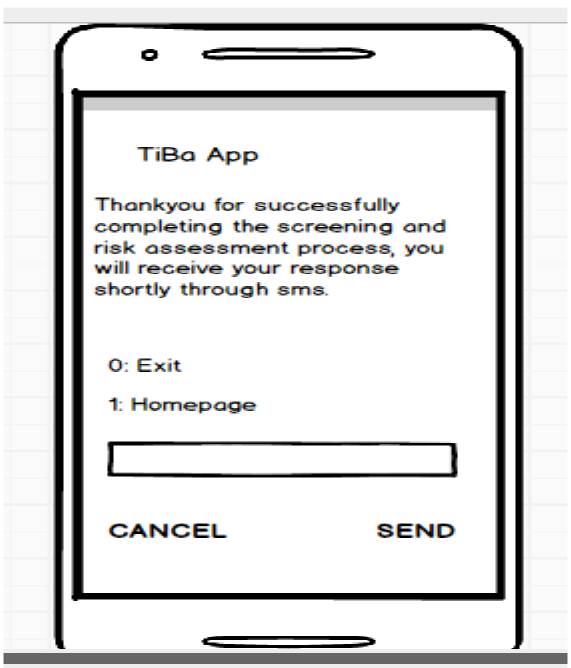


Figure C. 7 Notification status wireframe

Android Application Wireframes

Figure C. 8 Login Wireframe

Figure C. 9 Main Menu Wireframe

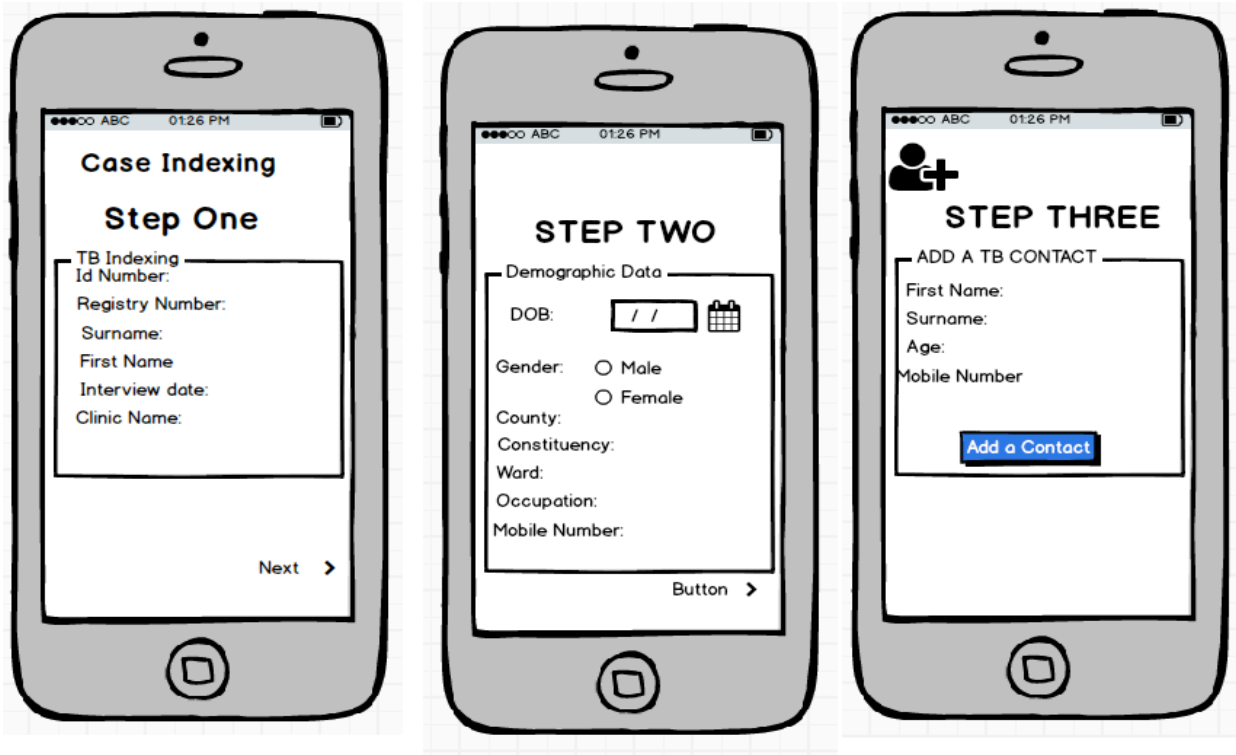


Figure C. 10 Case Indexing and adding TB contact wireframe

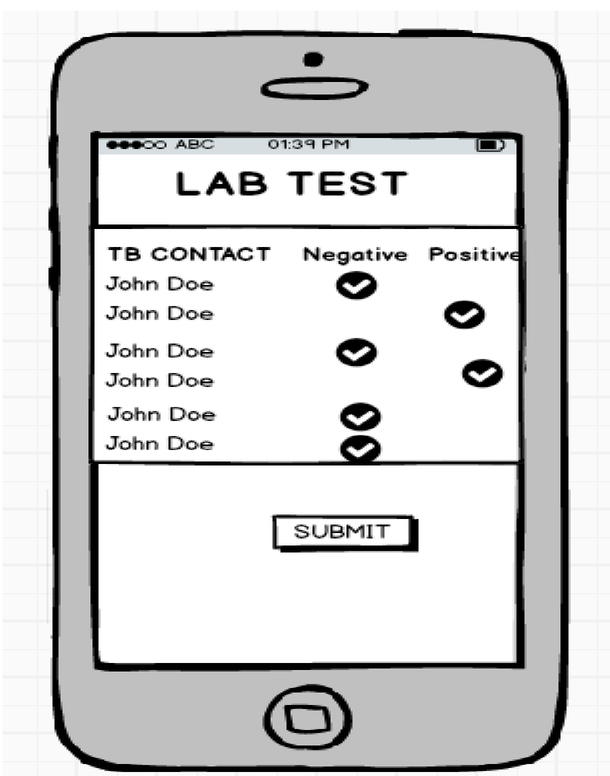


Figure C. 11 Labtest recording wireframe

Web Application Wireframes

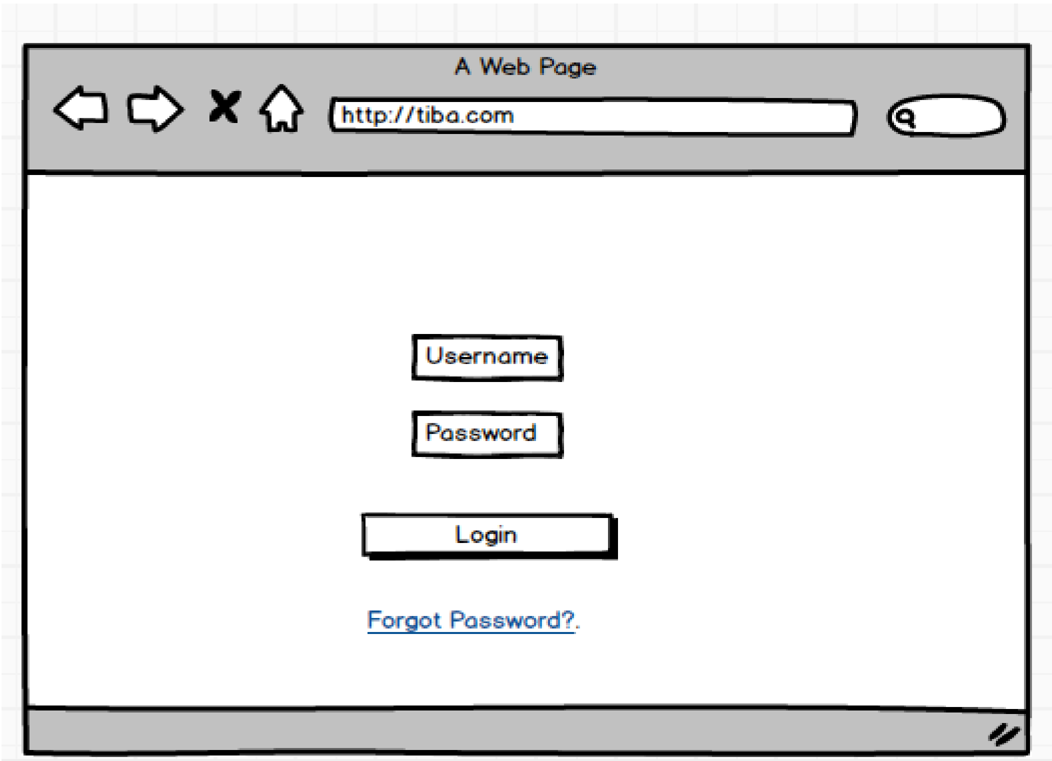


Figure C. 12 Web Application Login Wireframe

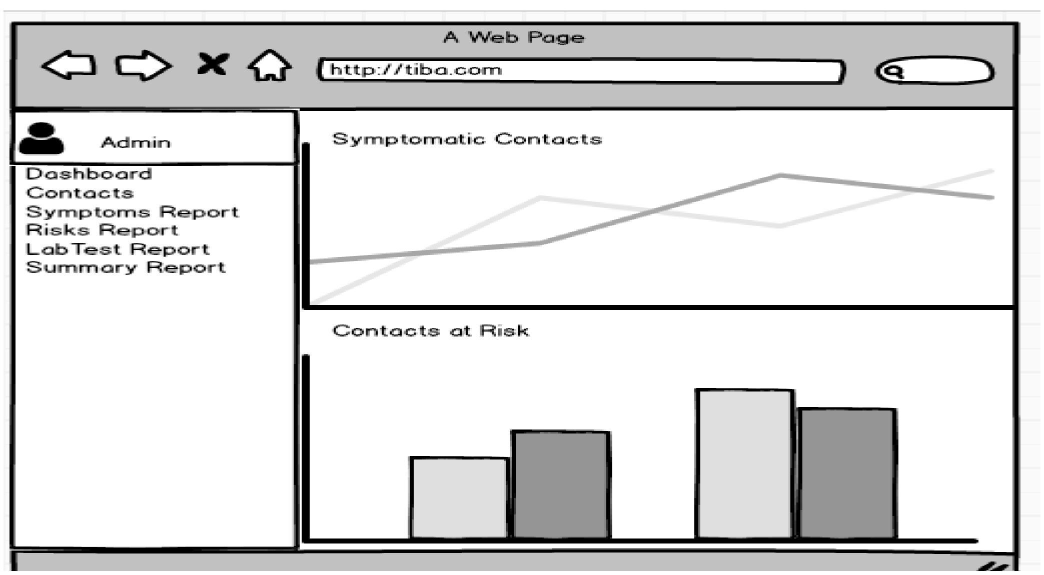


Figure C. 13 Web dashboard Wireframe

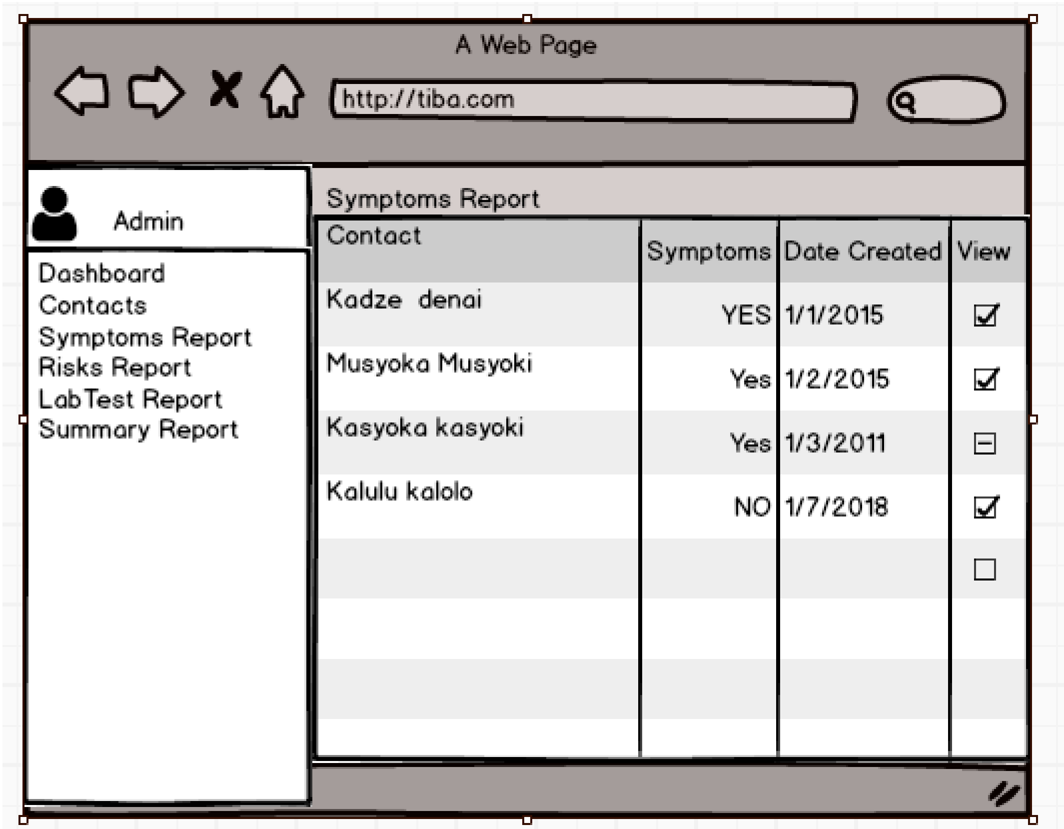


Figure C. 14 symptoms report wireframe