ENABLING SECURE MATERNAL HEALTH INFORMATION EXCHANGE USING BLOCKCHAIN.

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A Thesis Submitted to the Institute of Postgraduate Studies of Kabarak University in Partial Fulfillment of the Requirements for the Award of Master of Science in Information Technology.

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OCTOBER 2021

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The thesis entitled "**Enabling Secure Maternal Health Information Exchange Using Blockchain**" written by Musabi Antony Guya is presented to the Institute of Postgraduate Studies of Kabarak University. We have reviewed the thesis and recommend it to be accepted in partial fulfillment of the requirements for the Master of Science in Information Technology.

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DEDICATION

To my Mum Geraldine Nanjala and the entire family for the immense support accorded to me towards this journey.

ABSTRACT

Medical facilities in Kenya have made efforts to adopt Electronic Health Records systems at various levels and for different use cases. However, there lacks a robust and secure system for sharing sensitive and confidential health records curtails the potential benefits that can be gained by shared electronic health records especially the antenatal care process. Current methods do not provide comprehensive data integrity and non-repudiation of patient medical history as the patient seeks care from one provider to another. This situation is even dire and most detrimental to the most vulnerable of citizens, in expectant mothers, children and marginalized groups. These shared electronic health records that include provision of historical health information is critical to facilitate the making of informed medical decisions. There is need to solve these concerns on the confidentiality of patients' records adequately by introducing data encryption and patient mediated record access. As a result, thereof, a blockchain-based solution would reliably address these concerns and result in access to better quality maternal healthcare services in Kenya. This study focused on developing a Blockchain based model for secure Maternal Health Information Exchange. The solutions targeted inter health facilities information interchange while ensuring data protection and access to information. This study-utilized design thinking methodology to guide the research process. For empathize stage, a purposive sampling was undertaken, and discourse analysis was done to design the model. The ideate stage arrived at a model that was developed into a prototype. The results were evaluated and validated using a goal-based evaluation methodology with a formative-assessment test regime with the aim of improving the weaknesses of the current information exchange within the Antenatal Care (ANC) process. The results of the validation significantly approve the use of the blockchain model within the Antenatal Care (ANC) domain. The results also aided and improved information exchange and will guide future research in blockchain for healthcare provision and improve the body of knowledge in Information Communication Technologies. As a generalisation and extension into other domains, the research concluded that blockchain-based model is important in medical institutions that value historical transactions, specifically, the Antenatal Care (ANC) process. As a recommendation for further study, the research can be extended to integrate blockchain model applications for purposes of providing data exchange in the areas of health such postnatal, family planning follow-ups, outpatient sections and specialists' consultation clinics within the field of health.

Key words: *Electronic Health Records systems, Confidentiality, Blockchain, m-health.*

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ABBREVIATIONS

ACH	Antenatal Care Health
ANC	Antenatal Care
API	Application Programming interface
CRDM	Collaborative Requirements Development Methodology
DDBMS	Distributed Database Management Systems
DLT	Distributed Ledger Technologies
e-Health	Electronic Health
EHRs	Electronic Health Records
EOCs	Emergency Operation Center System
HIE	Health Information exchange
HIS	Health Information System
ICTs	Information Communication Technologies
m-Health	Mobile Health
P2P	Peer-to-peer
POC	Proof of Concept

OPERATIONAL DEFINITION OF TERMS

Blockchain: Blockchain, is a growing list of records, called Blocks, which are linked using cryptography. It allows industry participants to keep track of digital currency transactions without central recordkeeping. Each node (a computer connected to the network) gets a copy of the blockchain, which is downloaded automatically (Don & Tapscott, 2018).

Antenatal Care: Is a preventative healthcare provided in the form of medical checkups, consisting of recommendations on managing a healthy lifestyle and the provision of medical information such as maternal physiological changes in pregnancy

Distributed Ledger Technologies: Refers to the technological infrastructure and protocols that allows simultaneous access, validation, and record updating in an immutable manner across a network that's spread across multiple entities or locations (Frankenfield, 2021).

Health Information Exchange: This is an electronic transmission of healthcare-related data among medical facilities, health information organizations companies that oversee and govern the exchange of this data (Williams, Mostashari, Mertz, Hogin, & Atwal, 2017).

Health Information System: This is a system that unifies data collecting, processing, reporting, and use of information necessary for enhancing the efficacy and efficiency of health services through better management at all levels of health services (ONC, 2016).

Maternal Health: Maternal health is the health of women during pregnancy, childbirth and the postpartum period and maternal health care services are antenatal care (ANC), delivery care and postnatal care (PNC) services (Kifle et al., 2017).

CHAPTER ONE

INTRODUCTION

This chapter gives a brief background of the main concepts and problems informing this study specifically on the achievement of universal health coverage in Kenya by enabling a secure health information exchange using blockchain. It further proceeds to state the research problem, outlines the research objectives and defines the scope, significance and the expected outcomes of the study.

1.1 Background of the Study

Like other developing countries, the current government for the period 2017 – 2022 has prioritized the achievement of universal health coverage in Kenya. There is a key focus on the following areas as part of these efforts: reproductive health, maternal health neonatal, child and adolescent health (MOH, 2016). To this end, the Kenyan government has made a number of key efforts such as the introduction of free maternity with an aim of increasing access to skilled delivery service, beyond zero campaign, aiming to improve maternal and child health outcomes in the country, among others (Njuguna, Kamau, & Muruka, 2017).

However, these efforts are yet to bear much fruit; the offering of these services is still largely facility specific and relies on manual records where data captured are retained by the patients and at the same time transcribed on a clinical register for the health facility so that health facilities can have a record of the encounters (Bowman, 2013). Much of this intervention is evident in antenatal care process; during this care process, professional health workers normally use the Antenatal Health Cards as a medical tool for recording a patient data (Fagbamigbe & Idemudia, 2017). The data in these registers form the basis for compilation of required routine reports (Chawani, 2014).

This, as a result prevents continuity of care when mothers move from one location to another, Incomplete and inconsistency of data collection, inaccurate and unreliable reports, records redundancy, data inaccessibility, missing data in the records due to regular oversight, and data being difficult to read, as records grow so large over time (Fagbamigbe & Idemudia, 2017).
In addition, the process is tedious and difficult to extract data from it for clinical research and reporting in health centers. (Kihuba E., 2014); (Chao, 2016). Ordinarily, pregnant mothers

take their ACH cards home, creating risks of losing information and failed continuity of the care when the cards are misplaced or lost.

The challenge of ensuring continuity of care is one that has been addressed in many other settings such as National Commission on Correctional Health Care (NCCHC), policy health projects Kenya, through the use of ICT's. The Kenya Government has also recognized that e-health and m-health solutions as a key strategic direction towards achieving this goal and is ably captured in the Kenya National e-health policy 2016 – 2030 for the maternal and other health programs. To address the challenges facing the effective application of e-health Kenya Government through the ministry of health has outlined a number of key measures in the e-health policy 2016 – 2030. Key among these measures is the development of platforms for cross-border and inter facility sharing of health information about the medical incidences and history of patients without compromising privacy (MOH, 2016).

Health Information Exchange

Health Information Exchange (HIE) is a dissemination system for medical or healthcare data between different parties. It involves mobilization of health care information electronically across organizations within regions, community or hospital system (Williams, Mostashari, Mertz, Hogin, & Atwal, 2017). Consequently, it guarantees accuracy by ensuring, every party involved in a patient's care whether in a primary care setting, a specialists' health institutions have access to the same information.

Healthcare providers interact in health information exchange which in-turn helps facilitate coordinated patient care, reduce duplicative treatments and avoid costly mistakes (Athenahealth, 2018). HIE encourages efficient care by enabling automatic appointment reminders or follow-up instructions to be sent directly to patients, and prescriptions directly to pharmacies which reduces the amount of time patients spend filling out paperwork and briefing their providers on their medical history, allowing more time for discussions making on health concerns and treatments (Williams, Mostashari, Mertz, Hogin, & Atwal, 2017).

By saving time for patients and providers along the entire continuum of healthcare delivery, HIE has the potential to reduce costs and improve health outcomes thus becoming an intervention intended to address the threats to quality, safety, and efficiency posed by inaccessible or missing information at the point of care (WHO, 2016). However, in review of the problems, a number challenges are being faced in achieving these goals i.e., lack of integrated ICT systems, lack of the requisite infrastructure for the secure capture, storage and sharing of this information. Nevertheless, despite of having many efforts to address these challenges there is still no solution in place in the country.

Similar challenges have been addressed by use of various ICTs e.g., District Health Information System 2 (DHIS2) for data management), KenyaEMR, to support the care and treatment of HIV/AIDS among others (Muinga, et al., 2018). While many approaches have been examined for the solution of this challenge, there is still no solution that is presently able to achieve what blockchain has through its design patterns i.e., multiple stakeholder participation, distributed ledger and digital transactions (Zheng, Xie, Dai, & Chen, 2017). These challenges can be addressed in part by the adoption of blockchain technology as a solution (Andoni, et al., 2018).

Blockchain, originally blockchain, is a growing list of records, called Blocks, which are linked using cryptography (Don & Tapscott, 2018). Each block contains a cryptographic hash of the previous block known as the timestamp, and transaction data. It is an open, distributed ledger. It can record transactions between two parties efficiently and in a verifiable and permanent way (Iansiti & Lakhani, 2018). By design, a blockchain is resistant to modification of the data.

The first and probably most well known implementation of blockchain technology is Bit-coin, but there has been a massive expansion of blockchain use-cases since Bit-coin's initial introduction. In particular, blockchain and its smart contract capabilities have the potential to address healthcare interoperability issues, such as enabling effective interactions between users and medical applications, delivering patient data securely to a variety of organizations and devices, and improving the overall efficiency of medical practice workflow (Zhang, White, Schmidt, & Lenz, 2017). Interoperability challenges between different provider and hospital systems pose additional barriers to effective data sharing (Gordon & Catalini, 2018).

Blockchain replaces the centralized infrastructure with a distributed one (Marino, 2016). The blockchain software runs on thousands of nodes distributed across an entire network. To process a transaction, it is distributed to all the network nodes, and the transaction is cleared when the nodes have reached a consensus to accept the new transaction into the common ledger. The process is technologically sophisticated, but it replaces entire record keeping and transaction processing institutions (Ivan, 2016). This lowers transaction overhead in terms of price and execution time. It also means there is no single point of failure, providing a more robust, safer infrastructure (Szewczyk, 2017).

In a healthcare context, transactions would consist of documentation of specific episodes of healthcare services provided (Szewczyk, 2017). Healthcare providers, payers and patients would contribute encrypted data, which would reference a patient ID, to a public blockchain. This could include clinical data that is stored in EHR systems today, claims history and gaps in care from payers and family history and device readings from patients (Azaria, Ekblaw, Vieira, & Lippman, 2016). This information would be encrypted and stored in the blockchain and could only be decrypted by parties that have the patient's private key (Zyskind, Nathan, & Pentland, 2015).

1.2 Statement of the Problem

Medical facilities in Kenya have made efforts to adopt Electronic Health Records systems; however, lack of a robust and secure system for inter and intra medical sharing sensitive and confidential health records curtails the potential benefits that can be gained by shared electronic health records especially the antenatal care process. Current methods do not provide comprehensive data integrity and non-repudiation of patient medical history as the patient seeks care from one provider to another and some still rely on manual data records. While the lack of coordinated effort affects all medical cases, this study focuses on maternal health information exchange, which is most detrimental to the most vulnerable of citizens, in expectant mothers, children and marginalized groups. This study therefore seeks to develop a blockchain model for health information exchange to address the challenges of inconsistency, unreliability and security of medical records in maternal healthcare.

1.3 Objectives of the Study

Overall Objective

The overall objective of this study is to develop a Blockchain distributed ledger model for Enabling Secure Maternal Health Information Exchange.

The specific objectives of the study include:

i. To determine the challenges of health information exchange in maternal healthcare.
ii. To design a blockchain based model for health information exchange in maternal healthcare.

iii. To implement the blockchain based model for health information exchange in maternal healthcare.
iv. To evaluate the suitability of the blockchain based model for health information exchange in maternal healthcare.

1.4 Research Questions

This study is guided by the following research questions;

i. What are the challenges of health information exchange in maternal healthcare?
ii. How can health information; blockchain model for maternal exchange be designed?
iii. How can a health information; blockchain model for maternal exchange be implemented?
iv. How can the suitability of a blockchain based model for health information, exchange in maternal healthcare be evaluated?

1.5 Significance of the Study.

Concerns for confidentiality of patients' records must adequately be addressed through measures such as data encryption and patient mediated records access. A blockchain based solution would reliably address these concerns and result in access to better quality healthcare service. Provision of secure health data will be beneficial to healthcare providers for health information interchange. The government through patient insurance for example, NHIF schemes and other private entities can use the same platform for proper and efficient health care and institutional planning.

1.6 Scope of the Study

The scope of this study-entailed development of a blockchain distributed ledger model, building and testing prototype of the model within Nakuru Level 5 Hospital. This study does not overlap already existing models towards health information exchange within the maternal healthcare or be concerned with provision of healthcare between patient and health care providers within the maternal healthcare facilities.

1.7 Justification for this Study

Pregnant women and their fetuses have long been regarded as vulnerable, where being vulnerable indicates a likelihood of suffering harm (Ballantyne & Rogers, 2016). This can happen from anywhere regardless of whether they have carried their antenatal cards or not. It would therefore be prudent to ensure that their health records are accessible through a secure and interoperable system without impediments. This can be achieved through a blockchain-distributed ledger.

With regard to social implication, secure centralized access to patient's records eliminates delays in health record access thus potentially reducing maternal mortality and morbidity, time taken to make a decision by health experts, which in turn make a major difference in saving a patient's life. Patient's follow-up is much easier since decision makers do not have to make disjoint decision upon every new diagnosis.

Economically a distributed ledger makes sense since a patient who was diagnosed at one facility and the results uploaded in the ledger will not have to undergo the same test again. This improves the cost of health care for the expectant mothers. The cost of buying prenatal booklets is eliminated.

1.8 Assumption of the study

This study takes assumptions that the government hospitals and health institutions will collaborate in this research by providing express access to their facilities, data information and personnel. It also an assumption that all respondent to be interviewed will provide accurate information on the challenges faced and personal experiences in the interaction with the current available health information systems.

1.9 Limitation of the Study

This study will only be undertaken in public hospitals. Maternal health information from private hospitals will not be captured. The Model and prototype developed in this study will only be undertaken for blockchain technology. Patient data is not accessible due to privacy and security rules.

1.10 Conclusion

This chapter has presented a background of the main concepts and problems informing this study specifically on the achievement of universal health coverage in Kenya by enabling a secure maternal health information exchange with the use of a distributed ledger technology.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter presents a critical appraisal of the related literature review to the study of maternal health information exchange that is so crucial in provision of healthcare to mothers. It also presents a discussion on the usage of blockchain technology, distributed ledger technology and uses of blockchain in e-health and related technologies in various other studies by various other researchers. The theoretical and conceptual frameworks are also presented here leading to and guiding how the methodology for this study will be used and implemented.

2.1 Health Information Systems

The Demand for electronic health information exchange among health professionals is increasing along with other efforts to improve health care delivery quality, safety, and efficiency (Health-IT, 2016). Significantly, the requirements for use, new approaches to payment that affects coordination of care and federal financial incentives all drive the interest and demand for exchange of health information through health information systems (ONC, 2016). Health Information Exchange enables health care professionals and patients to access and share the vital medical information of a patient electronically and securely improving the speed, quality, safety and cost of patient care (Health-IT, 2016).

Electronic health information system provides the underpinnings for decision-making and has four key functions: data generation, compilation, analysis and synthesis, and communication and use (WHO, 2010). The HIS collects information from relevant health facilities, analyses them and ensures their overall quality, relevance and timeliness, and converts information into forms to be used within health institutions (WHO, 2010).

A good health information system brings together all relevant partners to ensure a seamless reliable, authoritative, useful, understandable, comparative data (Sinhasane, 2019).

2.1.1 Global Use of HIS.

Globally Health information systems tend to targets efficiency and data management whose drives are data analytics, collaborative care and cost control. The priority for implementing HIS in healthcare settings is squarely focused on improving the delivery of healthcare services and positively impacting patient health outcomes, which are popular amongst patients, caregivers, and healthcare professionals (Deloitte, 2018). HIS include system of record technologies such as EHRs, mobile health (m-health), and electronic health (e-health) solutions. These technologies operate across the healthcare ecosystem serving different types of stakeholder engagement e.g. clinician-to-patient, clinician-to-clinician, and patient-to-patient (Grossmann, Goolsby, Olsen, & McGinnis, 2011). HIS have become increasingly embedded in the delivery of healthcare services resulting in the development of HIS to acquire, store, maintain, and share health related data, providing sophisticated data analysis and decision support to relevant stakeholders.

2.1.2 Health Information Systems in Kenya.

In Kenya, the development of e-health and m-health policies has facilitated large number of projects with the use of ICTs to address health and health systems challenges (Njoroge, 2017). With the National ICT policy and e-Government strategy already in force, the health sector in Kenya envisions efficient, accessible, equitable, secure and consumer friendly healthcare services enabled by ICTs. Some technology bases projects within include:

a) Medical Inventory Management system MIMS was initiated for automating the medical supply chain to grant access to real time, accurate information on transactions in the supply chain from the dispensaries in the field to the district stores (Bmz.de, 2014).

b) Text for Adherence System (T4A System)/ USHAURI - a mobile platform has been developed with the objective of improving the health outcomes of the PLHIV by providing timely and reliable messages including appointment reminder messages, treatment adherence messages and wellness messages (m-health K., 2018)

c) Text for Life System (T4L System) - A mobile Platform that facilitate communication with donors through phone short message texting service (SMS) with the purpose of mobilizing donors to increase blood donations, increase repeat donations response to emergency blood appeals and return for test results. The system also enables the

Kenyan National Blood Transfusion Services to receive blood stock information from the regional blood centers and satellites through a mobile platform (m-health K., 2018).

d) Emergency Operation Center System (EOC System) - The EOC is a system developed for the Emergency Operation Center of the Kenya Ministry of Health, Department of Disease Surveillance and Response Unit. The system aggregates the data collected both for immediate disease reportable conditions and for public health events from DHIS2 and provide a channel that alerts the relevant authorities for response. The system also allow input of other disease and public health events from any other relevant data source, including the daily EOC call registers, live news channels, newspapers, the internet and social media (m-health K., 2018)

e) mLab System - The mLab system is aimed at improving the availability and timeliness of test results for EID/PCR, viral load and CD4 count from reference/testing labs to ordering facilities. It sends SMS messages containing laboratory results through a secure and confidential platform to the designated caregiver at the healthcare facility thereby cutting down on the turnaround time and improving on timely interventions on care and treatment (m-health K., 2018).

f) Care for the Carer System (C4C System) - C4C is a mobile based system developed to support Health Care Workers (HCW) with the objective of providing a reporting platform for occupational exposure incidents, tracking non-HIV conditions & creating scheduler for HCWs to increase antiretroviral therapy (ART) adherence and follow up. The mobile technology system will enable HCWs to register into the platform, report exposures and receive adherence messaging (m-health K, 2018)

g) EID/PCR Testing SMS printers - The SMS printers project was initiated with the objective of facilitating the timely delivery of Early Infant Diagnosis (EID) Polymerase Chain Reaction (PCR) and Viral Load (VL) results from testing laboratories to health facilities in order to minimize morbidity and mortality in HIV exposed infants and people living with HIV (PLHIV) (m-health K, 2018)

h) mPEP System - Mobile application using SMS that helps health care works (HCW) report occupational injuries that would potentially expose them to HIV and other infectious disease. Upon the uptake of Post Exposure Prophylaxis (PEP) treatments, the system would send those reminders and help in increasing uptake and thus increase adherence and maintain PEP compliance (m-health K, 2018).

2.1.3 HIS in Maternal Care in Kenya

Health data is generated from many sources; individuals, health facilities, disease surveillance sites, the community and geographical areas or units. The data is then summarized, analyzed and used at the district, province and the national levels depending on needs. Data is transmitted from these sources to the districts, then to the provinces and to the national level. Feedback loops exist at all levels. Within the health sector, data management is either paper based or electronic in different parts of the country. Data is collected manually paper based and reported to the districts where it is summarized and analysed, then transmitted to the national level through the province.

2.2 Challenges of Health Information Systems

In developing countries like Kenya, maternal and child, health is gaining concern due to increasing cases of morbidity and mortality. One of the key challenges in the Kenyan health sector identified in First Medium Term Plan of Vision 2030 document is weak health information systems (MOH, 2009). Various weaknesses identified in the existing information systems include lack of policy and guidelines, inadequate capacities of HIS staff, unskilled personnel handling data, lack of integration, many parallel data collection systems, and poor coordination, amongst others (MOH, 2009). Overall, the current HIS provides limited information for monitoring health goals and empowering communities and individuals with timely and understandable information on health.

Use of ICTs in the healthcare sector also creates its own set of concerns. These includes the right to privacy of individuals and the protection of this right in relation to health information and the development of suitable standards for regulating the provision of healthcare services by the use of technology (Chao, 2016). Proper regulation of the creation and use of healthcare information is imperative and is a matter of special concern to the government as well as other stakeholders in the field of healthcare (MOH, 2009).

The policies need to address two important aspects; First the need to gather and disseminate accurate and timely information on the incidence and prevalence of diseases, assessment of healthcare and public health needs and evaluation of programs, services, institutions and healthcare providers. Secondly, need to protect information from uses or disclosures that can cause harm particularly to individuals and institutions to which the information pertains (MOH, 2009).

Respect for confidentiality is vital to safeguard the well-being of patients and assurance of confidence of society within the doctor-patient environment (Beltran-Aroca, 2016). Health information is not only based on objective observations, diagnoses, and test results, but also subjective impressions about the patient, their lifestyle, habits, and recreational activities among others (Beltran-Aroca, 2016). Shared medical record also refers to the patients' ability to access their real-time, in-progress personal health information during a care process i.e. during a hospitalization and/or treatment (Planetree, 2017). Consequently, concerns for confidentiality of patients' shared records must adequately be addressed through measures such as data encryption and patient mediated records access.

The development of electronic health care, also called e-health, improves patient safety and facilitate efficient use of limited resources (Rynning, 2007). The introduction of electronic health records (EHRs) makes the possibility of immediate, even automatic transfer of patient data, for health care, across institutions, regions or national border. Data can be shared and used more effectively for quality assurance, disease surveillance, public health monitoring and research within medical facilities or institutions of such. E-health may also facilitate patient access to health information and medical treatment and is seen as an effective tool for patient empowerment (Lavin, 2015). At the same time, e-health solutions may jeopardize both patient safety and patients' rights, unless carefully designed and used with discretion (Rynning, 2007).

The growth in HIS/HIT has not been without challenges. The lack of integration across HIS globally is a serious roadblock to embedding these technologies as part of clinical/medical professional practice from primary healthcare to tertiary settings. In their m-health Green Paper, the European Commission (2012) outlines a number of these obstacles, including the wide range of health applications available, which makes choice difficult, a lack of evidence and quality control regarding their safety and cost-effectiveness. A lack of interoperability between solutions, a lack of processes/infrastructure for prescribing health applications, a lack of professional guidelines for technology use, malpractice liability concerns, data privacy and security concerns, a lack of reimbursement models for remote care by physicians/healthcare professionals or for self-care, a lack of reimbursement for patients' purchases of applications and wearable devices among others.

2.3 Blockchain Technology

Blockchain is a continuously growing list of records called blocks, which are linked, and secured using cryptography with each block typically contains a cryptographic hash of the previous block, a timestamp and transaction data (Verma, 2018). It can also be identified as an allotted ledger a few individuals in a peer-to-peer network that allows an individual to preserve information and execute contracts or agreements within the network (Thorsten, 2017). Completed data in all transaction are normally recorded in the public ledger and updated through an agreement of the participants in the system (Christian Catalini, 2017).

2.3.1 How Blockchain Works

The fundamental principles of Blockchain technology include (Malviya, 2017).

i. Distributed Database

Each participant on a Blockchain network has access to the complete information and its complete ledger. No single participant controls the information or the data. Each participant will validate the records of its transaction partners directly, without any third-party partner.

ii. Peer-to-Peer Transmission

In Blockchain, communication happens directly between peers rather than on a central server. Peer to peer allows crypto currencies or data to be transferred, without the need of any intermediaries or central server. Every node store and share information to any or all-alternative nodes

iii. Transparent.

Every action of nodes on network and associated values are visible to anyone with access to the system. Each node, or user, on a Blockchain is digitally signed by a unique 30-plus-character alphanumeric address that identifies it. Users will opt to stay anonymous or give proof of their signature to others. Transactions occur between Blockchain addresses.

iv. Static Records

Once a transaction is posted to Blockchain network, the records cannot be tampered. As a result, they are synced to each transaction record that was posted in past (hence the term “chain”). Various machine algorithms and approaches are enforced to ensure that the storing of the information is permanent, chronologically ordered, and readily available to any or all others on the network.

v. Computational Logic

The digital nature of the ledger means Blockchain transactions are often tied to computational logic. Therefore, users will use pre-defined algorithms and rules that mechanically initiate transactions between nodes.

2.3.2 Blockchain Systems Taxonomy.

Blockchain system can be divided into three categories.

i. Public Blockchain

A Blockchain that anyone in the world can read, anyone in the world can send transactions to and expect to see them included if they are valid, and anyone in the world can participate in the consensus process - the process for determining what blocks are added to the chain and what the current state is (Buterin, 2018). Example: Figure 1.

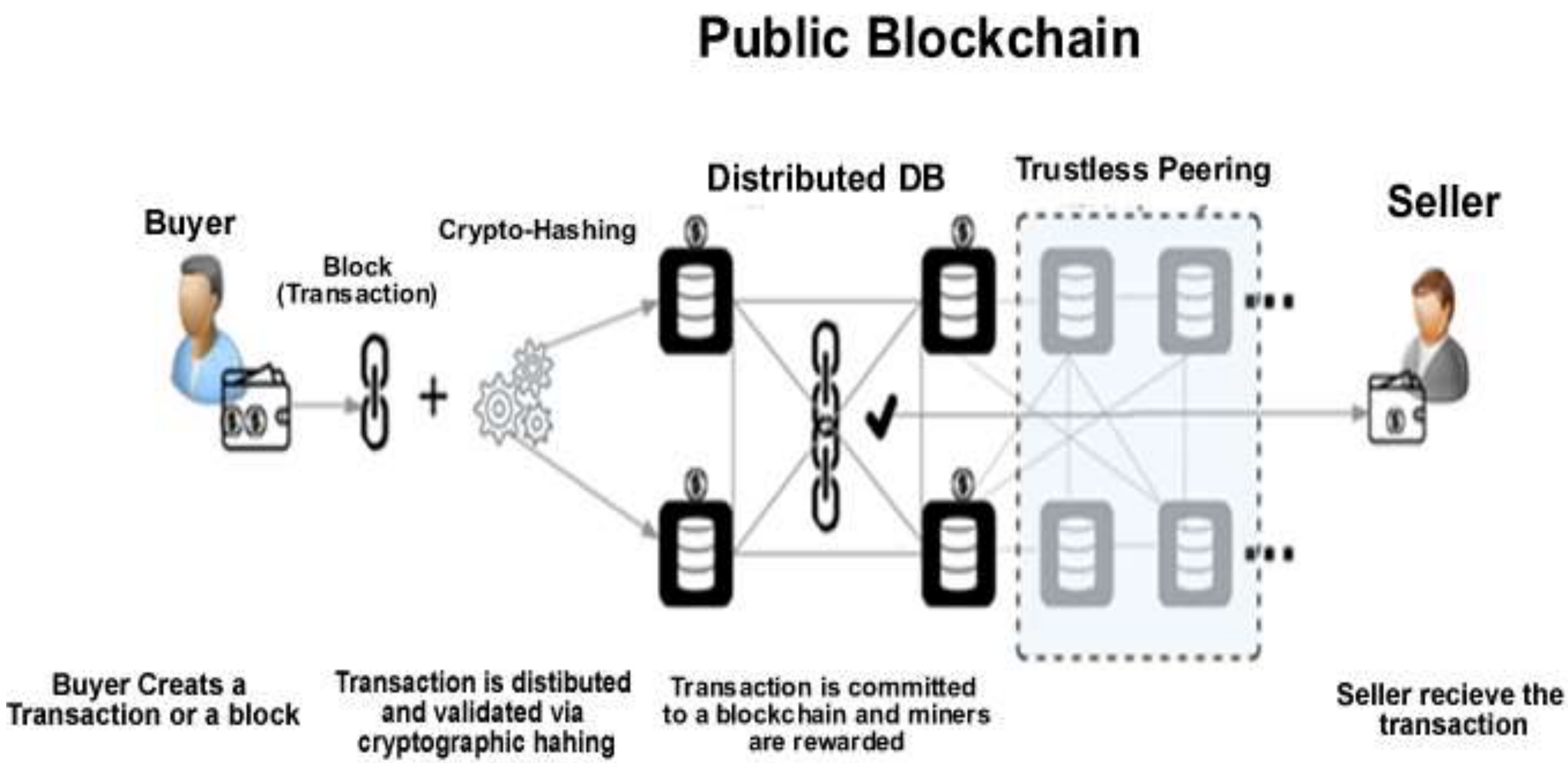


Figure 1: Public Blockchain. Source :(Steemit, 2016)

ii. Fully private Blockchain

A fully private Blockchain is a Blockchain where write permissions are kept centralized to one organization. Read permissions may be public or restricted to an arbitrary extent (Buterin, 2018), example Figure 2 .

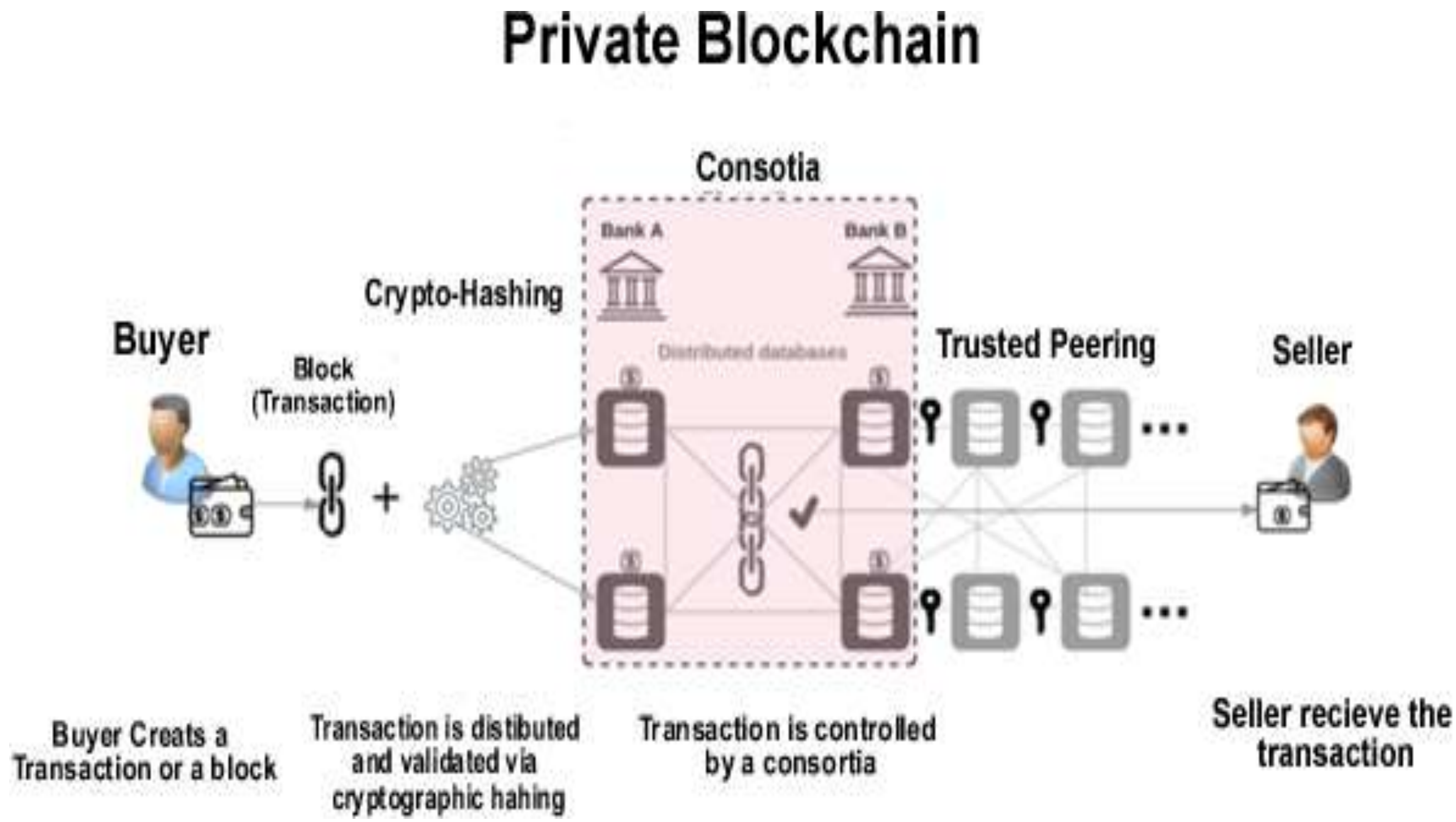


Figure 2: Private Blockchain. Source :(Steemit, 2018)

iii. Consortium Blockchain

A Blockchain where the consensus process is controlled by a pre-selected set of nodes; for example, one might imagine a consortium of 15 financial institutions, each of which operates a node and of which 10 must sign every block in order for the block to be valid (Buterin, 2018). These Blockchains may be considered "partially decentralized" Example Figure 3.

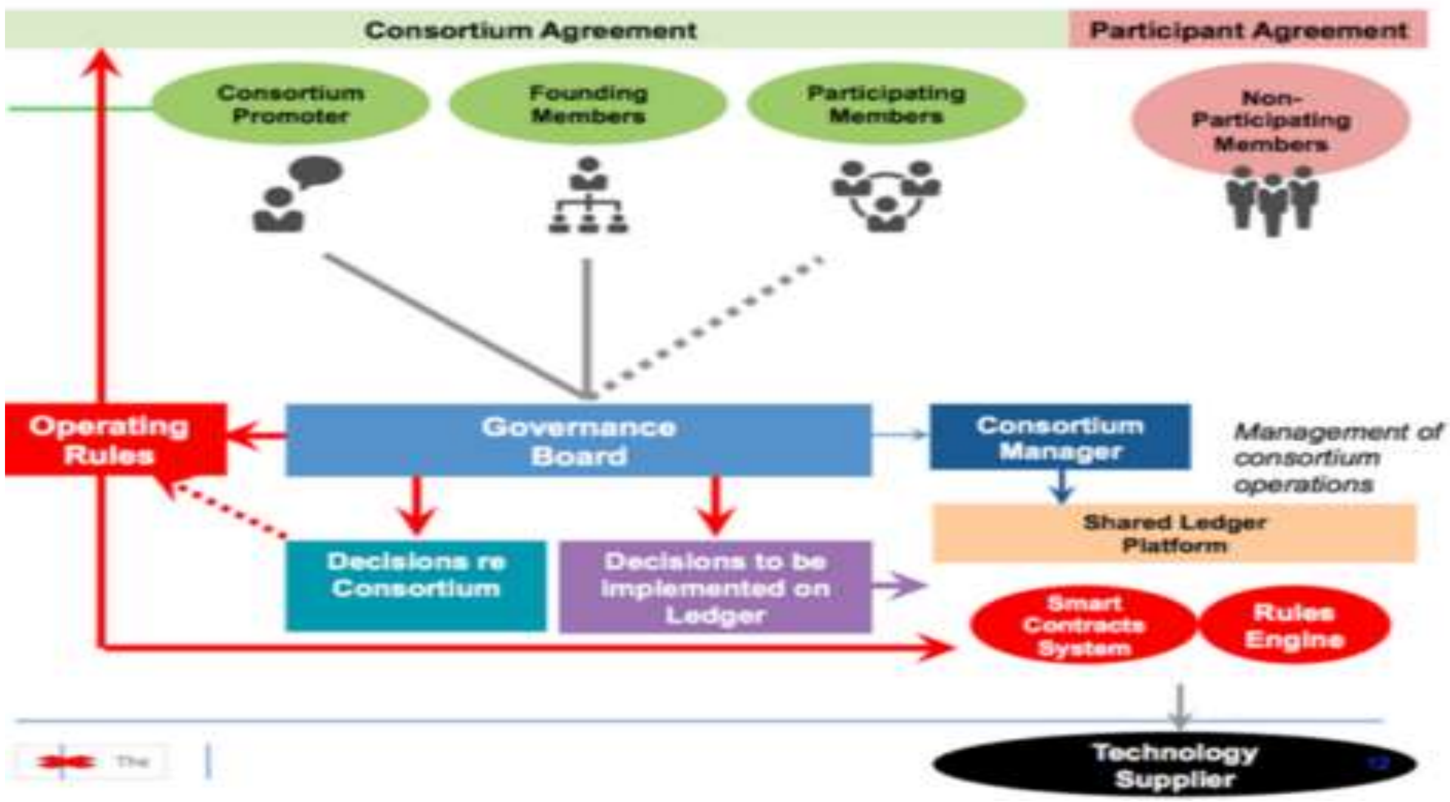


Figure 3: Private Blockchain. Source :(Gayan S., 2019)

2.3.3 Global Usage of Blockchain Technology

i. Smart Contracts

Smart contracts are computer protocols that facilitate, verify, execute, and enforce the terms of a commercial agreement (Kiviat, 2015). Applications and data providers have already used such structure within centralized computers. A case example involves digital rights management markets where the US law has been embedded into digital files to prevent a user from changing any transaction. Blockchain technology allows users to design contracts that are automatically executed following a trigger event, without having to rely on some form of third-party monitoring and enforcement mechanism (Thorsten Koeppl, 2017).

ii. Decentralized Digital Identity

A decentralized digital identity system is a source of truth where every single data element, such as user attributes and credentials, that can be included in the system only by distributed consensus. This encourages a single centralized source of truth. Users within a system get more control over their identity as they can share it only with trusted parties. No single centralized entity can tamper with user identities or data. (Andoni, 2018).

iii. Health Data and Pharmaceuticals

Addressing a lack of transparency in health data and improving trust on patient privacy through scalable health data exchange can be achieved using blockchain by supporting information exchange across various data types, from clinical trials to evidence data (Magee, 2018).

Within the pharmaceutical sector, tracing movements of drugs between manufacture and consumption, bring much-needed clarity to the supply chain through the use of the technology. Units of medication are each given individual serial numbers at the point of production. Using blockchain, as each item moves through the supply chain, additional verified information is appended. Blocks of data cannot be tampered with and are collectively validated by all stakeholders. The result is an end-to-end system that is simpler and more secure than anything we have seen before (Magee, 2018).

iv. Decentralized cloud storage

Decentralized platforms have the potential to giving upgrades to the cloud storage industry in terms of security and privacy. Other aspects are the decrease in cost, and the ability to increase storage capacity to make more income within industries (Zwanenburg, 2018).

2.3.4 Benefits of Blockchain for Biomedical/Health Care Applications

Key benefits of Blockchain distributed ledger technology that makes it feasible for biomedical and health care applications solutions compared to traditional methods include:

i. Decentralized Management.

Distributed database management systems are always logically centralized-managed while Blockchain is a peer to-peer, decentralized database management system. Therefore, Blockchain is suitable for applications where independently stakeholders within a healthcare setup can collaborate with one another without controlled central management intermediaries (Tsung-Ting Kuo, 2018).

ii. Immutable Audit Trail.

Blockchain only supports create and read functionality compared to traditional methods with creates, read, update, and delete functionality. This enhances difficulty in changing data records making Blockchain suitable technology as an unchangeable ledger to record critical information for audit trail purposes (Bigchain, 2018).

iii. Data Provenance.

Cryptographic protocols provides that the ownership in a Blockchain transaction can only be changed by the owner and on the other hand the origins of the assets are traceable increasing the reusability of verified data this feature make DLT suitable in managing critical information such as patient consent records (Trent McConaghy, 2016).

iv. Robustness and Availability.

Although DDBMS and Blockchain are based on distributed technology and thus do not suffer from single-point-of-failure, it is expensive for DDBMS to achieve the high level of data redundancy but Blockchain does since each node has a whole copy of whole historical data records. Therefore, Blockchain is suitable for preservation and continuous availability of records e.g., electronic health records of patients, which is important (Martin L., 2018).

v. Security and Privacy Using Cryptographic Algorithms.

Bitcoin Blockchain utilizes the 256-bit Secure Hash Algorithm (SHA256), a cryptographic hash function defined in the US Federal Information Processing Standards 186-4, published by the National Institute of Standards and Technology (Khatwani, 2018), as the cryptographic hash function in the hash-chain that the proof-of-work algorithm runs on. In the algorithm, SHA-256 is used to generate user addresses for privacy and anonymity improvement where each user is represented by a hash value instead of a real identity (Khatwani, 2018). Bitcoin Blockchain exploits the 256-bit Elliptic Curve Digital Signature Algorithm, an asymmetric cryptography algorithm defined in the US Federal Information Processing Standards 180-4 (Virunurm & Seeba, 2017), to generate and verify high-security-level public and private keys as digital signatures, and thus ensures ownership of the digital assets, as with patient records (Kuo, Kim, & Ohno-Machad, 2017).

2.4 Distributed Ledger Technology in Health Care Systems

Blockchain technology has the potential to transform healthcare, placing the patient at the centre of the healthcare ecosystem and increasing the security, privacy, and interoperability of health data (Deloitte, 2018). Health information exchanges (HIE) will be made efficient, disintermediate, and secure with the provision of new models through the technology. Healthcare industry has drowned in huge data files i.e. clinical trials, patient medical records, billing transactions, medical research results and many more (Marr, 2017). The most likely application in the healthcare could be:

i. Data Management

Blockchain can provide patients and their providers' one-stop access to their entire medical history across all providers. Economics of time, money and duplication in procedures will be achieved (Iqbal, 2018). Regardless of the medical centers and institutions that patients visit during their lifetime, blockchains would allow all data to be processed in a single location, and the patients themselves will track and monitor all their data (Obradovic, 2019).

ii. Supply Chain Integrity

Data from patients', previous use of medicines and their results are tall order in scientific researchers. With Blockchain systems access to such data can be made easy but only from

patients' consent. Doing so will also discourage fake companies to produce counterfeit drugs that cost pharmaceutical companies millions in loss annually (Iqbal, 2018).
To design supply chain solution, "FarmaTrust" is a platform, based on Blockchain technology to improve drug supply chain integrity by focusing on eliminating of counterfeit drugs proliferation and increasing efficiency in the pharmaceutical industry.

iii. Medical Research

Clinical trials are an important part of medical research and making the patients outcomes available for new treatment protocols, improve care and medicines. With healthcare systems full of diverse and disconnected records there is no way possibly for anyone to process that data for future uses. Distributed ledger can help arrange that data and provide access to make medical research easier (Iqbal, 2018). With the use of distributed ledger technology over time, Blockchain applications will becomes solution changer in the health industry.

2.4.1 The Need for Blockchain Technology in Healthcare.

Focus on quality health care services includes assurance of patient health management at a superior level at all times (Pratap, 2018). In Kenya the healthcare sector, critical patient data and information remains scattered across different departments systems and applications (Fabian, Nangami, Tabu, Mwangi, Ayuku, & Were, 2017). Due to this, vital information is not open and conveniently accessible in times when required. The existing healthcare environment cannot be considered complete as multiple players within the framework do not have a system in place for smooth administration considering having a number independent health programs/systems and services which all maintain their own vertical and uncoordinated reporting systems (Kirichu, Samuel, Nicodemus, & Jades, 2014).

Several interventions come in handy affecting the entire healthcare industry. Such interventions include:

1) Misuse of available data preventing healthcare organizations from delivering appropriate patient care and high-quality services (Pratap, 2018).
2) Keeping local records of the patient data in outdated systems which makes it difficult for doctors to diagnose using previous records, which is time-consuming for the doctor and tedious for the patients too left with the task of redoing some tests again.

3) Health Information Exchange, since patients do not have any control over their data, the chances of identity thefts, financial data crimes and spamming are at a rise (Pratap, 2018).

Despite the use of ICTs in most public and private healthcare facilities these days, there is still a challenge in collecting, analyzing, secure and exchange data seamlessly. Therefore, the healthcare industry needs a system that is smooth, transparent, economically efficient and easily operable (Eirini C., Theodoros C., Nicolai, & Christos N., 2018). With the introduction of Blockchain technology in healthcare sector, permission of numerous substances such as data transfer in the healthcare systems to remain in adjust and share information on a commonly disseminated record will be provided. With such a model input, individuals can share and keep track of their information and other exercises happening within the framework without having any extra alternatives for astuteness and security (Bidgoli, 2018).

2.5 Research Gaps

Table 1: Research Gaps

S/No.	Existing Approach	Description	Research Gap
1	**Kenya Maternal Health Care Process**	This is the process that guides to the health of women during pregnancy, childbirth and the postpartum period	- Manual Process - The antenatal process uses the ACH cards creating risks of losing information and failed continuity of care when misplaced (Antenatal Care Process) - Data collected manually (Paper Based) - Lack of interoperability - No comprehensive data integrity and non-repudiation of patients' medical history.
2.	**District Health Information System2 (DHIS2)**	DHIS2 is an open source, web-based health management information system (HMIS) platform used to aggregate statistical data collection, validation, analysis, management, and presentation. for daily data at the level of the health facility	- Used to aggregate statistical data collection, validation, analysis, management, and presentation. - Only based for data collection

3.	**Kenya Health Referral Process**	The health referral system is a process that allows a patient's wellbeing to be handled in a holistic way, using services beyond those available at the place from which they have access to treatment, whether in a community unit, pharmacy, health centre or higher-level health facility	- Information about patients on referral is mostly maintained in manual format. - Lack of interoperability. - Delayed referral completion. - Weak HIEs to capture referral data. - Poor transport arrangements for emergency referrals.
4.	**AID: Tech (Tanzania)**	Blockchain platform that facilitates sharing of digital health data to make women's antenatal care a far safer and effective	- Only used for data collection

2.6 Conceptual Framework

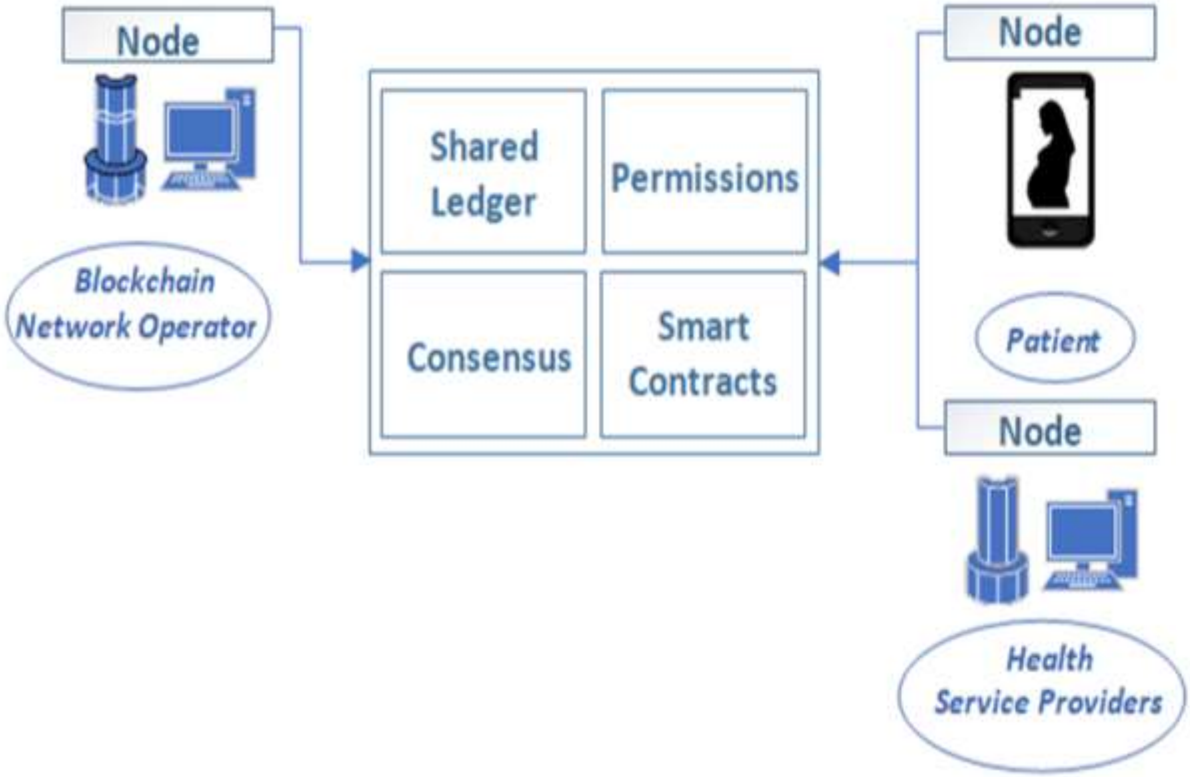


Figure 4: Conceptual Framework for Maternal Health Exchange Using Blockchain

(Source; Researcher)

The conceptual framework entails the following concepts:

The parties involved:

The following are the key participants involved in the system;

i. ***Blockchain Network Operator:*** This entity will develop and maintain the platform on an ongoing basis.

ii. ***The patient:*** The patient will be at the heart of the system as it is their records that will be managed. They will give consent to health service providers to access these records at the point of care.

iii. ***Health service providers:*** These will include antenatal clinics nurse who will access the system during the provision of service.

iv. **The Asset:** The primary assets to be tracked are the patient and for this specific use case the expectant mother.

v. **The Transactions:** The transactions to be recorded are the visits to health service providers where data on health status, diagnosis, tests, prescriptions and medication dispensed will be collected. The health service providers and the patient will jointly establish the validity of these transactions during the facility visit.

vi. **Shared Ledger:** This will store all the approved transactions generated at the various nodes and processing platforms. Once a transaction is approved, it will be replicated across the nodes with storage and processing platforms.

vii. **Permissions:** This will be a private and permissioned ledger where only authorized participants will be allowed to view and make changes based on their roles in the system.

a. Health service providers will be granted a view of relevant historical data necessary to provide care.

b. The ministry of health will have full access to the transactions in order to monitor compliance with regulations and for surveillance.

c. The auditors will have full access to the transactions in order to monitor compliance and adherence to acceptable practices in the health sector. **Consensus:** This will be enforced to ensure the validity of all transactions before they are recorded permanently and subsequently replicated.

viii. **Smart Contracts:** Self-executing and self-enforcing smart contracts will be considered to automate agreements and business rules in the system. The smart contract will be used to balance and send transactions over the blockchain network.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Introduction

This chapter discuss the methods that were used in the design, implementation and evaluation of the Blockchain distributed ledger model for Enabling Secure Maternal Health Information Exchange.

3.1 Overall Study Approach

This study utilized desk research and design thinking methodology. Desk research was used to achieve objective one of this study. Design Thinking is a design methodology that provides a solution-based approach to solving problems (Schönhals et al., 2018). It is extremely useful as it seeks to tackle complex problems, by understanding the human needs involved, re-framing the problem in human-centric design, by creating ideas in brainstorming sessions, and adopting a hands-on approach in prototyping and testing (Razzouk and Shute, 2012). It comprises of five stages: Empathize, Define, Ideate, Prototype and Testing.

To buttress these findings, design thinking methodology using empathizing and design was used to augment objective one. Objective two was achieved using ideate method of design thinking methodology while prototyping achieved objective three of implementation of the project. The final testing method of design thinking was used to test, and evaluate objective four of this study.

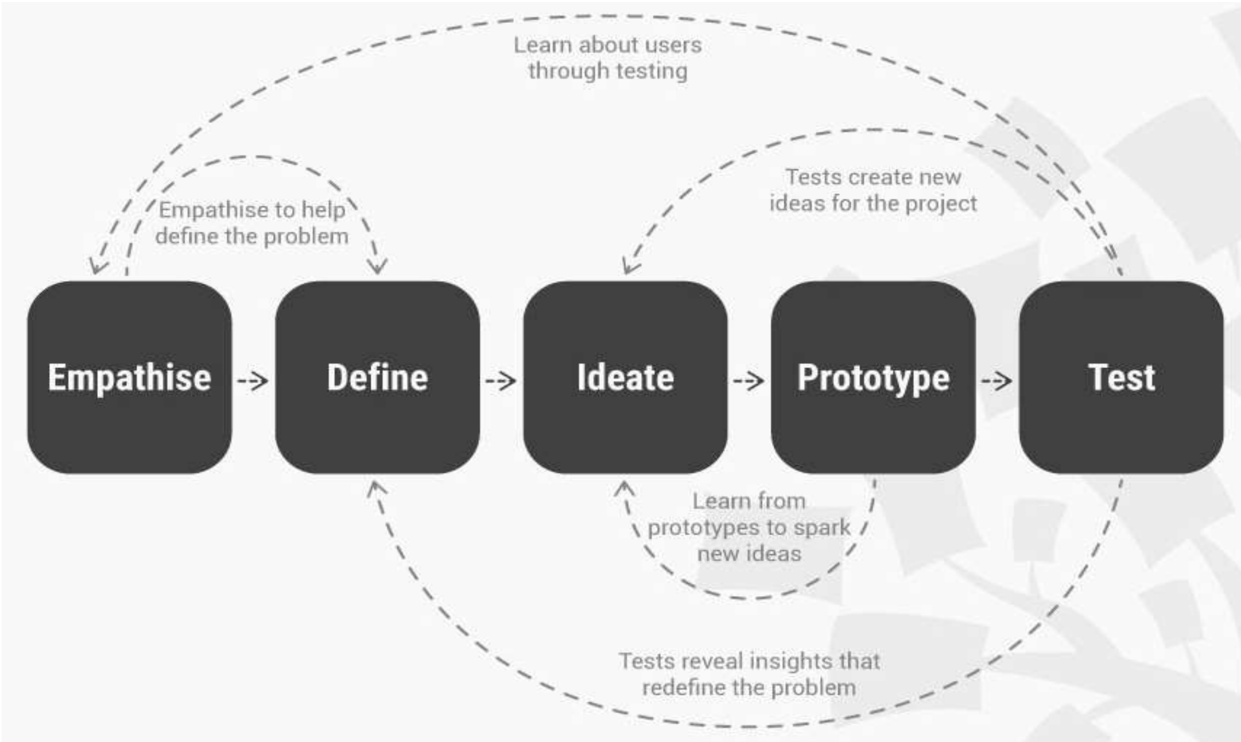


Figure 5: Design Thinking Flow Diagram (Source; Siang 2010)

i. **Empathy -** The first stage of the design thinking process allows a designer to gain an empathetic understanding of the problem. The process is crucial as it allows an individual to set aside assumptions about a problem and gain real insight into users and their needs.
ii. **Define -** This stage involves accumulation of the information created and gathered during the empathizing stage. It includes analyzing observations and synthesizing them to define the core problems within a specific domain.
iii. **Ideate -** This process entails looking for alternative ways to view the problem and identify innovative solutions to the problem statement created on the previous step.
iv. **Prototyping -** Prototyping is the turning ideas into tangible products. A prototype is a scaled-down version of the product, which incorporates the potential solutions identified in the previous stages.
v. **Test –** In this stage, the prototype is tested with the users to monitor the response and deem whether the solution satisfies the requirements gathered as a solution to the problem.

The design thinking process was adopted for this study as follows:

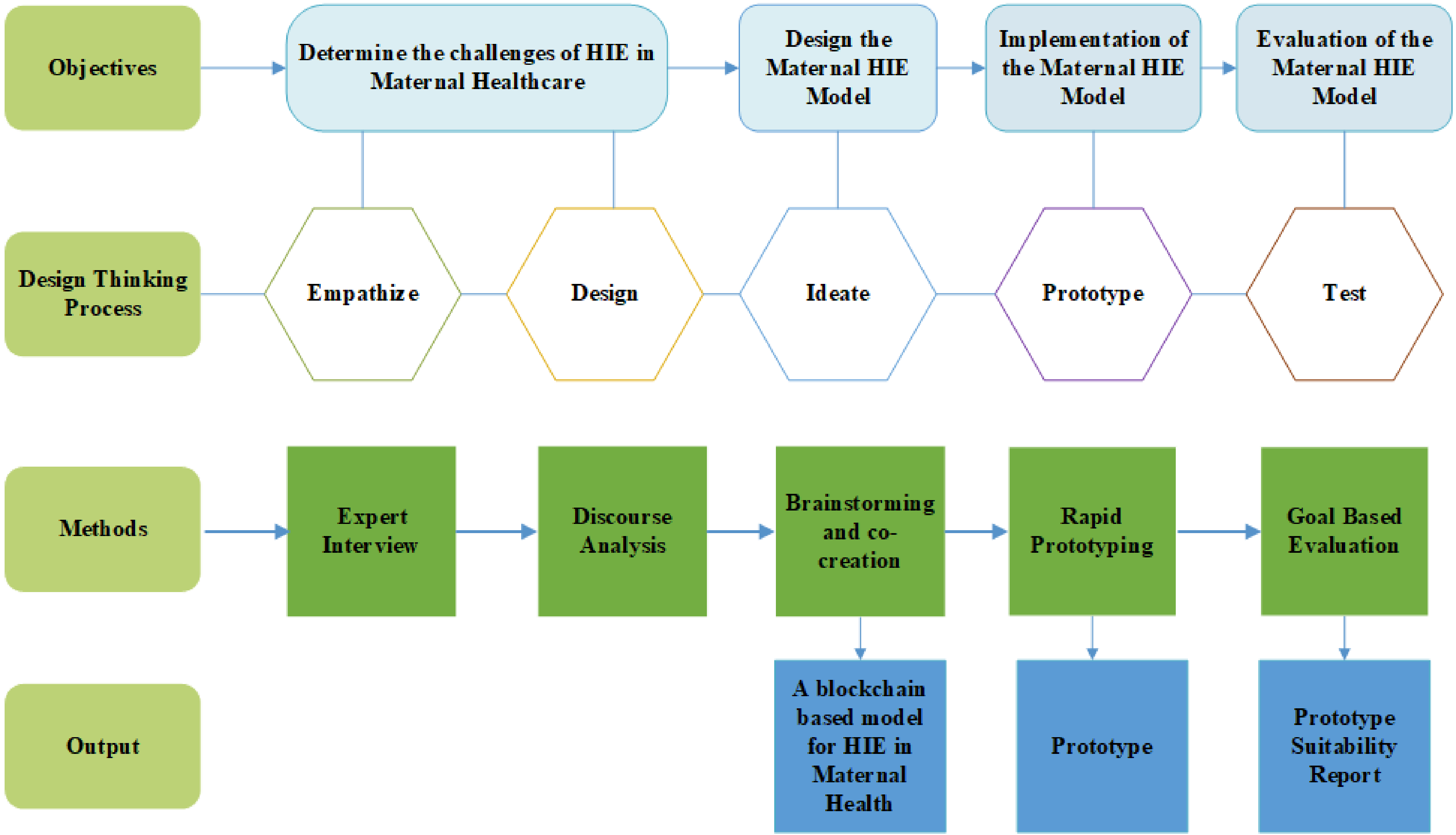


Figure 6: Design Thinking Process for the Maternal Health Information Exchange Model Using Blockchain (Source: Researcher)

3.2 Design of a Blockchain Based Model for Maternal Healthcare Information Exchange

The design of the model was undertaken as follows;

1. **Empathize**

In this study, the process entailed conducting expert interviews at the antenatal care clinic, records sections and the IT department within Nakuru County Level Five Hospital in Kenya. The interviewees (Nurse, a records officer, IT administrator) were chosen through their head of sections that positively identified the appropriate and experienced person within their section to give information in their area of expertise. These persons were those who had served the antenatal section understand the challenges of data handling and information exchange. The interviews sought to determine:

i) The current approach of Maternal Health data collection prior to Information Exchange within the maternal health care process.
ii) The challenges facing Maternal Health Information exchange within the maternal health care process.
iii) The current means of Maternal Health Information exchange within the various entities involved in maternal health care process.

2. **Define**

Discourse analysis is a qualitative method used to analyze interactions with people. It focuses on analyzing the social context in which the communication between a researcher and the respondent occurs (Socialcops, 2018). Additionally, it looks at the respondent's day-to-day environment and uses that information during analysis. In this study, the analysis of information from the interviews was done using this method.

3. **Ideate**

Ideation process entails use of the results gathered during analysis to generate logical ideas. With a solid understanding of user's requests and a clear formulation of a problem statement, potential solutions are shared out (Siang, 2010). Within this stage brainstorming and co-creation, which entails creative thinking, sharing of ideas and decision making with the team (Nurse, records officer, IT administrator) was done in order to come up with proper formulation of the solutions to the problem.

3.3 Model Implementation of the Maternal Health Information Exchange Using Blockchain

In this study, rapid prototyping approach in figure 7 was used in the implementation process of the Maternal Health Information Exchange Using Blockchain.

Rapid prototyping is the act of creating a low-fidelity object for testing a concept (Ranson & Lahn, 2017).

The process for the study is as follows:

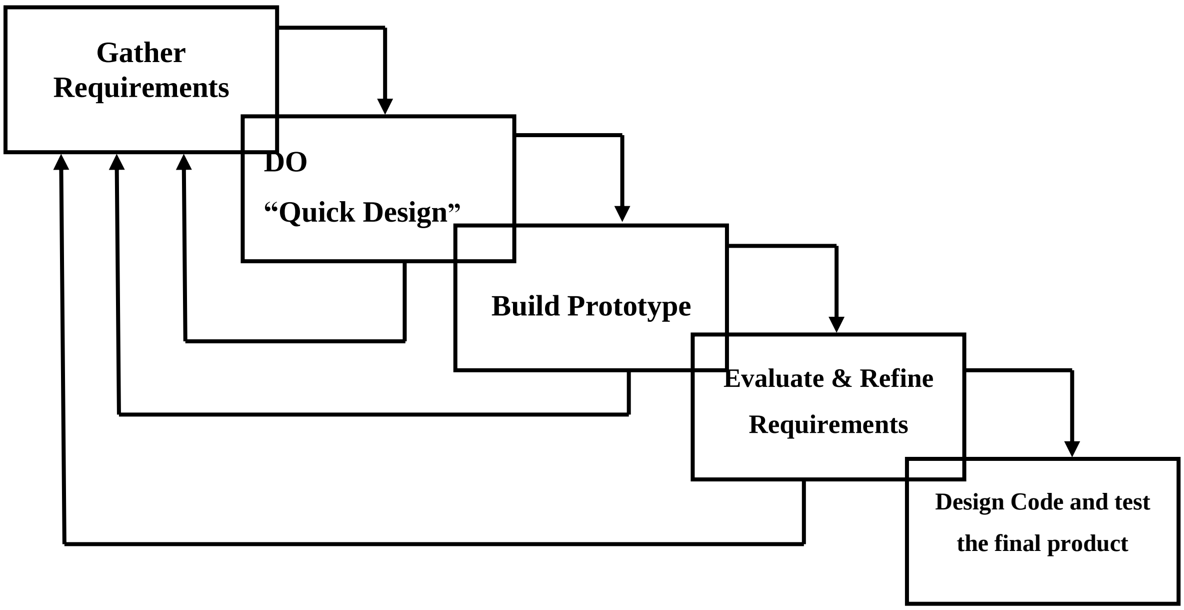


Figure 7: Rapid Prototyping Model (Source; NASA 2004)

i. Gather requirements

This step used the information gathered from the model developed in Objective 1 of the study. It entailed the interview output, the analyzed reports and the findings of the proposed solutions.

ii. Design the System

The solution, which involves model design, entailed the following process

a) Identify a Suitable Use-case.

Identification of proper use case that makes business sense, was done at this stage, which defined the purpose of the designed prototype. They include Data Authentication & Verification, Smart Asset Management, and Smart Contracts. In this study, smart contacts were used.

b) Identify the Most Suitable Consensus Mechanism.

A Proper consensus mechanism for the maternal information exchange was identified. In this study, the Proof of stake consensus mechanism was used.

c) Identify the Most Suitable Platform

Based on the consensus mechanism (Proof of Stake) the Ethereum platform was used in the design.

d) Designing the Blockchain Nodes

The nodes within the maternal health information exchange model were permissioned on a private blockchain platform running on a windows operating system

e) Building the Application Programming Interface (APIs)

The APIs within this study are the smart contracts, which was used to transact information on a blockchain platform.

f) Design the Admin and User Interface

The design for the maternal health information exchange blockchain model admin and the user interface platform was done with the use of Solidity, a high-level programing language

iii. Build prototype

Building the prototype shall follow the following steps.

a) Environment Setup.

The following tools were installed.

1. **Solidity v0.5.7** - Solidity is a Programming Language for Ethereum's Smart Contracts. Smart contracts are programs, which govern the behavior of accounts within an Ethereum state (Rothrei, 2019). The solidity software was used for designing the smart contracts for the maternal health information exchange.
2. **Geth (go-Ethereum) v1.8.27** – This is a Command Line interface. It allows running of a full Ethereum Node (Beyer, 2019). In this study, Geth will facilitate interaction with ethereum frontier live network and mine real ether, enable transactions between addresses, create contracts to send transactions and explore block history.
3. **Ganache v2.5.6** – This is an Ethereum blockchain emulator used for development purposes. It creates a virtual Ethereum blockchain, and generates some test accounts that we will use during development (Nagpal, 2018). In this research, Ganache will be used for creating a personal Ethereum Blockchain for testing smart contracts.**Truffle v5** - Truffle is a development environment, testing framework and asset pipeline for Ethereum. Additionally, the truffle framework provides built-in smart contract compilation, linking, deployment and binary management automated

contract testing (Sahu, 2019). In this study, the truffle shall be you can used to deploy contracts, develop applications, and run tests.

b) Smart Contract Development

A smart contract is a computer protocol that facilities the transfer of digital assets between parties under the agreed-upon stipulations or terms in a blockchain platform. The steps for creating a smart contract are as follows:

1. Add truffle config file (truffle.js.) which will connect ethereum node running on local host.
2. Creating a contract (counter. Sol) which will define the Event, the variable and the methods in use
3. Deployment Script Add deployment script named as '2_initial_migration.js' for Counter. Sol
4. Write Truffle Test cases: Create test file named as counter_test.js for Counter contract in test folder.
5. Run test cases

c) User Interface Development.

The tools for user interface development are:

1. Metamask Version 6.5.3 - Metamask is a wallet that works as a browser extension. It effectively acts as a bridge between web browsers such as Chrome or Firefox and the Ethereum blockchain (Azaña, 2018).
2. Mist v0.11.1 - It is a user-friendly browser interface that communicates with Geth (go-Ethereum). Mist offers an overall view of the Ethereum blockchain and all needed tools to interact with the blockchain component like Ether and smart contracts (Langlois, 2019).

d) Prototype Testing

Prototype testing involved testing of the smart Contract before deploying it in a blockchain public network. All the components of the prototype were considered fit to its task once a transaction is complete and stored within the blockchain network.

3.4 Evaluation of the Maternal Health Information Exchange Using Blockchain Model

The Maternal Health Information exchange Blockchain Model was evaluated using Goal-based evaluation methodology of IT systems 'as such' and 'as is. Goal-based evaluation is a technical and economical evaluation approach whose main goal is measuring the extent to which software or an intervention has attained its clear and specific objectives (Nanda, 2019).

3.4.1 Goal base system as such

Evaluating Blockchain Model as such means to evaluate the Model without any involvement from users. In this situation, only the evaluator and the Model are involved (Cronholm & Goldkuhl, 2003). The data sources that could be used for this strategy is the Blockchain Model itself and documentation of the Model. This evaluation model was done based on the model design requirement gathered against the prototype design testing procedures.

3.4.2 Goal base evaluation as is.

Evaluating the Model in use was a formative-assessment for continuous improvement, which involved use case situation where a user interacts with the prototype itself. This analysis using formative-assessment is considered quite complex than the previous as such evaluation strategy. This strategy has the ability to provide a richer and deeper picture of the desired model output (Cronholm & Goldkuhl, 2003). In this exercise, the evaluation involved demonstrating the model to the experts (Nurse, Records officer, IT administrator) and gathering feedback to ascertain the suitability of the Maternal Health Information Exchange Blockchain Model.

3.4.3 Selection Criteria for Model Testing

In this study, purposive sampling technique was utilized with an objective of giving a logical representation of the population. Purposive sampling, also known as judgment, selective or subjective sampling refers to a sampling technique in which researcher relies on his or her own judgment when choosing members of population to participate in the study (Barratt & Shantikumar, 2018). An expert sampling type within the purposive sampling technique was used to glean more information on the data collection method and its challenges at the clinic from the expertise being interviewed. The expert being interviewed was an ANC nurse, a records officer and an IT administrator who were nominated for the study by their head of sections to give more details of the ANC process.

3.5 Ethical Consideration

During the requirement, gathering and model testing several ethical considerations were adhered to. The researcher sought to obtain information that furthered the purpose of the study towards coming up with a model. The ethical consideration was in line with regulating authorities. This was done through an introductory letter from the Institute of Postgraduate and Research of Kabarak University and a permit obtained from National Commission for Science Innovation and Technology (NACOSTI). The information obtained from either source for the purpose of the research was treated confidentially. In addition, the study sought not to use patient real data due to the sensitivity of information that curtails patient’s data and information.

3.6 Conclusion.

This section described the approach and methods that were followed in carrying out the study. The overall methodology utilized desktop research approach and design thinking methodology.

CHAPTER FOUR

MODEL DEVELOPMENT AND RESULTS

4.0 Introduction

This chapter discusses model development process, data collected results, model design, limitations, challenges, and results of the evaluation as per the research objective presented in section 1.3.

4.1 Challenges of Health Information Exchange in Maternal Healthcare.

This section presents the results for objective one of the study, which endeavored to determine the challenges of health information exchange in maternal healthcare. The objective was attained at stage one of the design thinking methodology. The methodology used to identify these challenges was achieved using literature review and expert interviews of the stakeholders within provision of maternal healthcare. The main guiding questions for the expert interview are presented in section 4.1.1

4.1.1 Results of Expert Interview

This section presents the results of the expert interview used to identify challenges and weaknesses of the existing Maternal Healthcare Information exchange model. The main interview questions that were used to identify and guide the analysis of the expert interview included the following:

i. **Question 1:** What is the current method used in sharing of information in the antenatal care process?

This research question sought to enquire on the kind of information captured from the mother. Further, the enquiry sought to find out if the information is manual or automated and whether copies of the same information captured are available. The question here enquired on the sequence of reports and technical capabilities of the mother.

A. Findings 1: The current method used in dissemination of information in the antenatal health care process.

A total of three experts were interviewed in this case an ANC nurse, an IT administrator and a Records Officer and the findings were

a) The current approach for the antenatal care process is still on a manual based where all pregnancy details must be recorded on the mother and baby booklet retained by a patient and the same information replicated on the Maternity Case Records in this case the Antenatal Care Register MOH 405.

b) The antenatal record can also act as a referral letter if a patient is referred to the next level of care and thus acts as a link between the various levels of care as well as the antenatal clinic and the labor ward consequently ensuring early detection and management of treatable complications.

c) According to the experts interviewed, there is no Health Information System currently in place for purposes of managing maternal health care at the hospital. The current method in use is manual, where the information gathered is summarized on the manual ANC reporting form as shown in figure 10. This reporting form provides a summary to be entered on the DHRS2 system.

   Some of the challenges iterated by the administrator include;

   i. Change management resistance.
   ii. Fear of technology
   iii. Extra workload. Users of the system feel like it's an extra task added to them.
   iv. Government procedures, protocols and bureaucracies

d) The hospital also indicated that there is a Hospital Management system (Q-Afya), implemented at the outpatient area.

e) All antenatal visits are always documented in an antenatal care register, and the task of filling each entry is designated to trained health care worker. The Caregiver accurately record each visit, and takes responsibility for maintaining neat and legible records.

f) On a weekly basis, a clinic supervisor coordinates the completion of the Antenatal care report and ensures that respective sections have made their submission in full and on time and also responsible for monitoring the upkeep of the registers, and for ensuring the completeness of record entries each day and ensure that all data is documented. Separate registers are stored in a central location once the summary of the report has been entered on the DHRS2.

ii. Question 2: What are the current approaches of maternal health information exchange within the antenatal health care process?

This research question sought to enquire about the current approaches of information exchange describing whether the process is conducted manually or is automated. It further sought to inquire on the role of the District Health Information System2 (DHIS2) within the antenatal health care process.

B. Findings 2: The current approaches of maternal health information exchange within the antenatal health care process.

This section presents the findings of current approaches used to exchange maternal health information. Currently, the method employed for information exchange and data collection within the maternal healthcare is still manual (Paper Based), where information captured is retained by the patient and at the same time the information is transcribed on a health register so that health facilities can have a record of the encounters. Within the Antenatal Care process, the Nurse uses the Antenatal Card as shown in Figure 8, as a medical tool for recording a patient data and the same data transferred to the Antenatal Health Register.

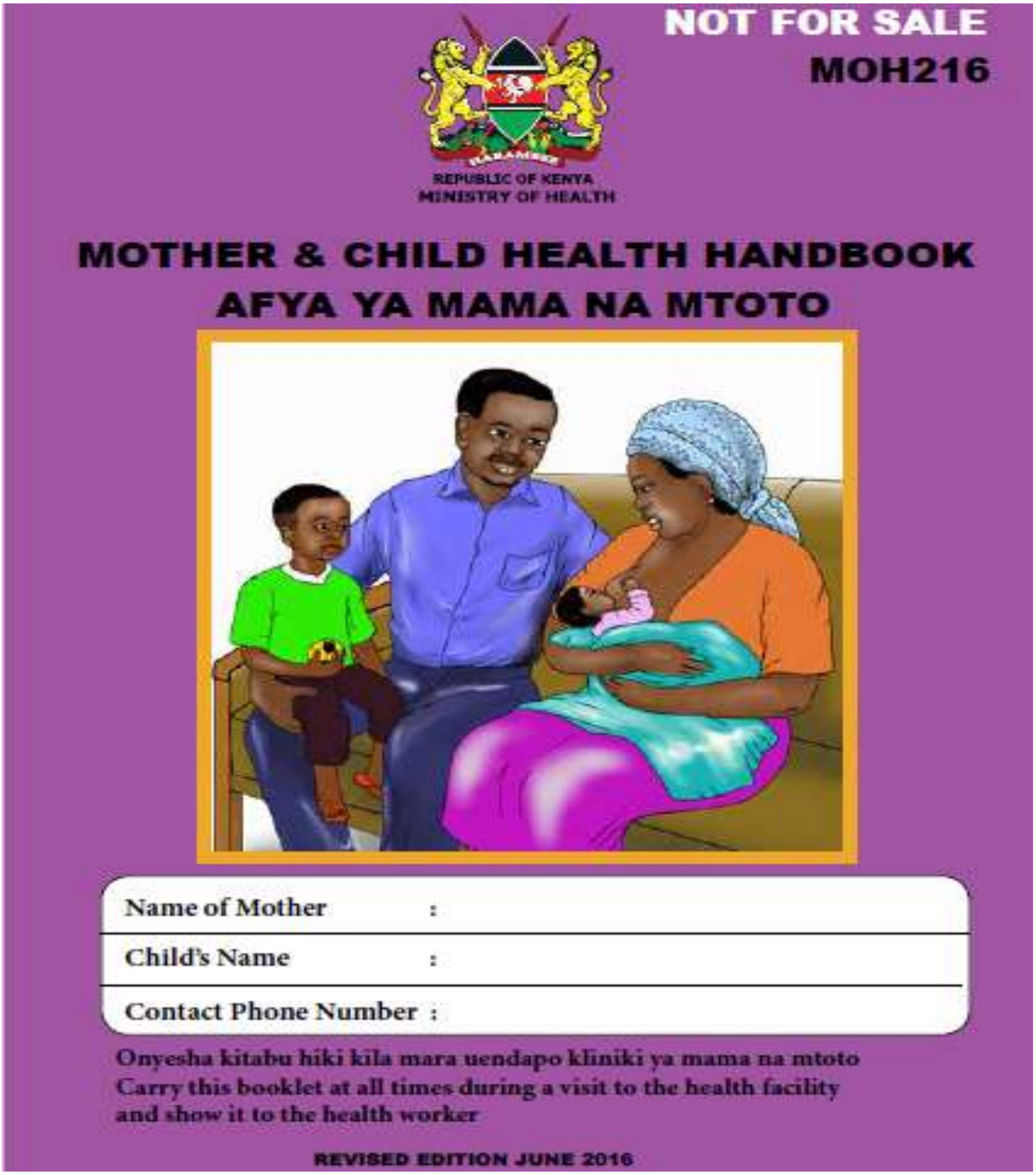
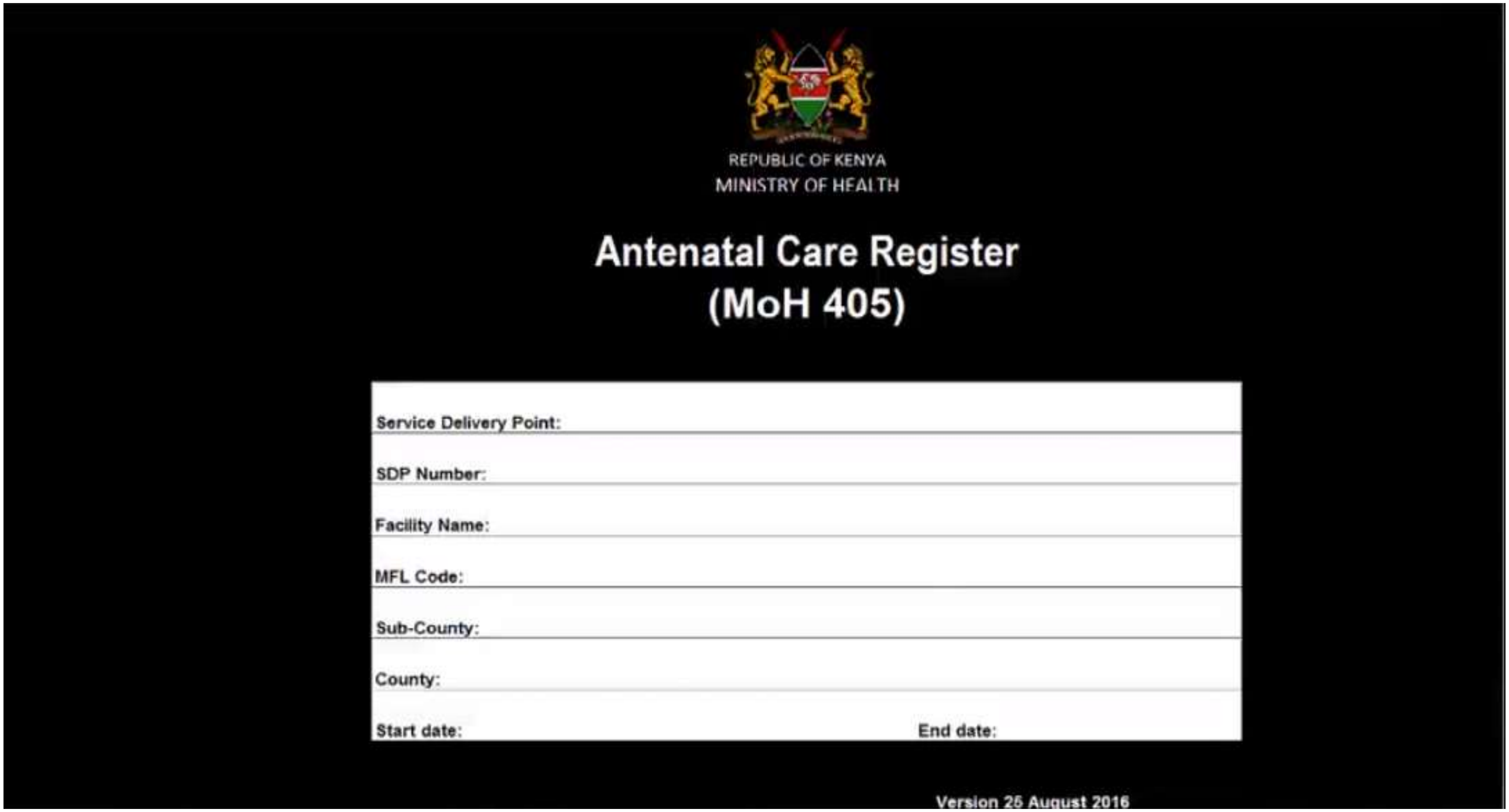


Figure 8: Antenatal Health Book (Mother and Baby Book).

The ANC card is source of health information, which complements information in the antenatal register and provides each expectant mother with an individual record of her medical and obstetric history (UNHCR, 2010). The card is carried at all times and updated after each visit alongside the antenatal care register (MOH 405).


REPUBLIC OF KENYA
MINISTRY OF HEALTH

Antenatal Care Register
(MoH 405)

Service Delivery Point:

SDP Number:

Facility Name:

MFL Code:

Sub-County:

County:

Start date: End date:

Version 25 August 2016

Figure 9: Antenatal Care Register MOH 405 Cover Page.

Ministry of Health   Antenatal Care Register   MOH 405   *Page 1*

																Laboratory				ART Eligibility		
																		HIV Results		Assesed through?		
Date of visit	Antenatal Clinic Number	1st Visit (Y)	Number of Visits	Full Names	Village/Estate	Age	Marital Status	Parity	Gravidae	Date of Last Menstrual Period (LMP) *(dd/mm/yy)*	Expected Date of Delivery (EDD) *(dd/mm/yy)*	Gestation in weeks	Weight (kg)	Blood Pressure	Counselled on...... *(Codes)*	Haemoglobin	RPR/VDRL	Initial P/N/KP/U	Retest Y/N (P/N/NA)	WHO Stage *(Stage)*	CD4	Start on ART in ANC *(Date)*
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)	(s)	(t)	(u)	(v)	(w)

No. New Clients (c): _____
No. Revisit Clients (d): _____
No. Completed 4th Antenatal Visit (d): _____
No. Clients with Hb < 7 g/dl (q): _____
No. Tested for Syphilis (r): _____
No. Syphillis positive (r): _____

No. Known HIV Positive at entry (s): _____
No. Tested for HIV (s): _____
No. Retested for HIV (t): _____
No. Tested HIV Positive(s) & (t): _____
Counselled as couple (am): _____
Male Partner Tested (an): _____

Assesed for ART Eligibility - WHO (u): _____
Assesed for ART Eligibility - CD4 (v): _____
Started on ART (w): _____

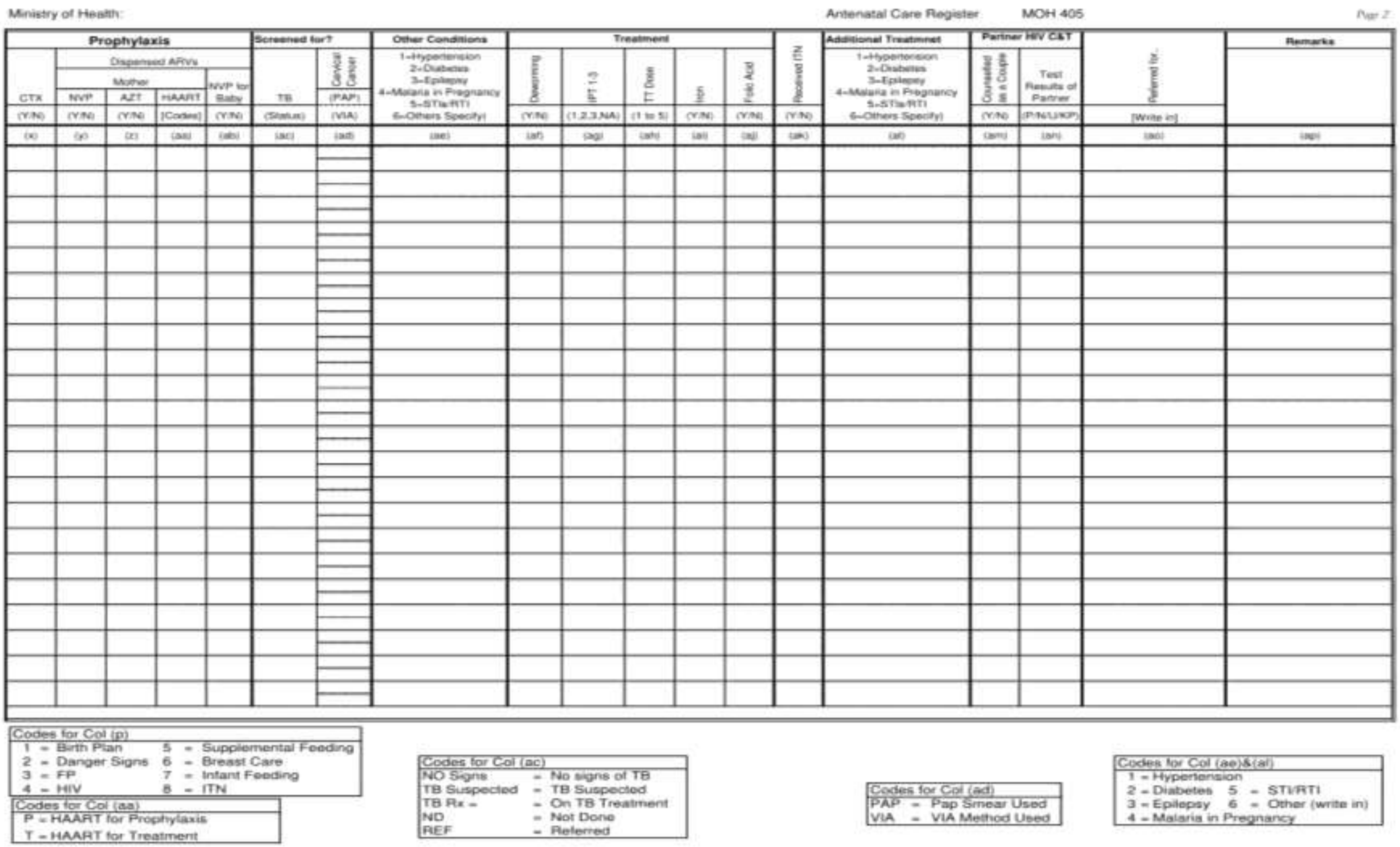
Screened for TB (ac): _____
Screened for Cervical Cancer (PAP) (ad): _____
Screened for Cervical Cancer (VIA) (ad): _____

Mother
NVP - (mother) (y): _____
NVP+AZT (y) & (z): _____
No. HAART for Treatment (aa): _____

Baby
NVP for baby (ab): _____

No. given IPT1 (ag): _____
No. given IPT2+ (ag): _____
No. of received ITN (ak): _____

Figure 10: Antenatal Care Register MOH 405Content Page A.



Ministry of Health: Antenatal Care Register MOH 405 Page 2

Prophylaxis					Screened for?		Other Conditions	Treatment						Additional Treatmnet	Partner HIV C&T			Remarks
	Dispensed ARVs																	
	Mother			NVP for Baby		Cervical Cancer												
CTX	NVP	AZT	HAART		TB	(PAP)	1-Hypertension 2-Diabetes 3-Epilepsy 4-Malaria in Pregnancy 5-STIs/RTI 6-Others Specify)	Deworming	IPT 1-3	TT Dose	Iron	Folic Acid	Received ITN	1-Hypertension 2-Diabetes 3-Epilepsy 4-Malaria in Pregnancy 5-STIs/RTI 6-Others Specify)	Counselled as a Couple	Test Results of Partner	Referred for..	
(Y/N)	(Y/N)	(Y/N)	[Codes]	(Y/N)	(Status)	(VIA)		(Y/N)	(1,2,3,NA)	(1 to 5)	(Y/N)	(Y/N)	(Y/N)		(Y/N)	(P/N/U/KP)	[Write in]	
(x)	(y)	(z)	(aa)	(ab)	(ac)	(ad)	(ae)	(af)	(ag)	(ah)	(ai)	(aj)	(ak)	(al)	(am)	(an)	(ao)	(ap)

Codes for Col (p)
1 = Birth Plan
2 = Danger Signs
3 = FP
4 = HIV
5 = Supplemental Feeding
6 = Breast Care
7 = Infant Feeding
8 = ITN

Codes for Col (aa)
P = HAART for Prophylaxis
T = HAART for Treatment

Codes for Col (ac)
NO Signs = No signs of TB
TB Suspected = TB Suspected
TB Rx = = On TB Treatment
ND = Not Done
REF = Referred

Codes for Col (ad)
PAP = Pap Smear Used
VIA = VIA Method Used

Codes for Col (ae)&(al)
1 = Hypertension
2 = Diabetes
3 = Epilepsy
4 = Malaria in Pregnancy
5 = STI/RTI
6 = Other (write in)

Figure 11: Antenatal Care Register MOH 405Content Page B

The data in these registers form the basis for compilation of required routine reports, given in a summary form Figure 12, which are entered on the DHIS2 on a monthly basis.

PGH Nakuru MOH 711

MCH/FP ANCclients

For the month of ……………………………………………………

Data element	New	Re-visits	Total
CWC Attendance			
ANC Attendance			
PNC Attendance			
FP Attendance			

ANC

Data element	No.
New ANC Cliets	
Re-visit ANC Clients	
Clients given IPT 1st Dose	
Clients given IPT 2nd Dose	
Clients with Hb <11g/dl	
No. of Clients completed 4 Antenatal Visits	
LLITNS distributed to children under 1 year	
LLITNs distributed to ANC clients	
ANC clients tested for syphilis	
ANC clients Syphilis +ve	
Mother counselled on infant feeding options	
Total women done breast examination	
ANC given exercises	
Adolescents (10-14 years) presenting with pregnancy	
adolescents (15-19 years) presenting with pregnancy	
ANC Client given Iron	
ANC Client given folate	
ANC Client Supplemented with Combine Iron and Folate	

Indicator	<25 yrs	25-49 yrs	50 Yrs and above	Total
Cervical cancer receiving VIA /VILI /HPV VILI / HPV				
Cervical cancer clients screened for Pap smear				
Cervical cancer clients screened for HPV test				
Cervical cancer clients with Positive VIA/VILI result				
Cervical cancer clients with Positive Cytology result				
Cervical cancer clients with Positive HPV result				
Cervical cancer clients with suspicious cancer lesions				
Cervical cancer clients treated using Cryotherapy				
Cervical cancer treated using LEEP				
HIV positive clients screened for cervical cancer				

Figure 12: MOH 711 ANC Reporting Tool.

Question 3: What are the challenges facing maternal health information exchange within the antenatal health care process?

This research question sought to enquire on the challenges faced by medical practitioners, the hospital administration as well as the mother who gets antenatal healthcare services from that facility. While their challenges are diverse and varying, the question is whether they are similar and whether providing a solution for one solve the challenge for another.

C. Findings 3: The identified challenges and weaknesses of the existing maternal healthcare information exchange models.

The literature review and expert interviews determined various challenges and weaknesses of the status quo. The current process does not allow continuation of data collection for use, since it prevents continuity of care when mothers move from one location to another. Incomplete and inconsistency of data collection, inaccurate and unreliable reports, records redundancy, data inaccessibility, missing data in the records due to regular oversight, and data being difficult to read as records grow so large over time (Abate, Salgedo, & Bayou, 2015). In addition, the process is tedious and difficult to extract data from it for clinical research and reporting in health centers (Abate, Salgedo, & Bayou, 2015) (Chao, 2016). The table 2 below shows the summary of literature that identified the challenges and weaknesses in the existing maternal health information exchange.

Table 2: Literature Review Findings

Researcher	Research title (publication)	Challenges identified
Abate, Salgedo, & Bayou, 2015	Evaluation of the Quality of Antenatal Care (ANC) Service at Higher 2 Health Center in Jimma, South West Ethiopia	a) Difficulty on extract data. b) Slow reporting c) Tedious and difficult to extract data
Chao, 2016	The impact of electronic health records on collaborative work routines: A narrative network analysis	a) High risk of losing information b) Failure continuity of the care when the cards are misplaced or lost.

(UNHCR, 2010)	UNHCR Module 9 Part 1 on Antenatal Care.	a) The antenatal care process and data collection is Manual, cumbersome and error prone
(Chawani, 2014)	A Cross-case Analysis of the Effects of EMR Deployment on Antenatal Care Services in Rural Health Centres in Malawi.	The following challenges were identified: a) Incomplete data. b) Inconsistent data collection. c) Inaccurate and unreliable reports
(Fagbamigbe & Idemudia, 2017)	Wealth and antenatal care utilization in Nigeria: Policy implications.	The following challenges were identified: a) Records redundancy b) Data inaccessibility c) Missing data
(Kihuba E., 2014)	Assessing the ability of health information systems in hospitals to support evidence-informed decisions in Kenya.	a) Tedious and difficult to extract data from for clinical research and reporting in health centers.
(Bowman, 2013)	Impact of electronic health record systems on information integrity: quality and safety implications. Perspectives in health information management	a. The finding indicates that the manual records are slow in data retrieval and entry and non-centralized in nature.

As a result of the challenges and weaknesses identified in the existing maternal health information exchange models in use today, the findings showed that various challenges are important to be identified and strategic solutions for the same sought so as to have a robust, reliable, efficient and effective maternal health information exchange model.

Table 3. Shades light on the key assessment criterion used to evaluate the existing health information system and expose their weaknesses on the basis of challenges and to inform the design of the proposed model.

Table 3: Assessment Criterion of Challenges in Information Exchange

S/N	Assessment Criterion	Traceability
i.	Accuracy of Data collected	**A.**
ii.	Continuity of Care	**B.**
iii.	Decentralization	**C.**
iv.	Non-Repudiation	**D.**
v.	Immutability	**E.**
vi.	Authentication	**F.**
vii.	Redundancy	**G.**
viii.	Data Stewardship	**H.**
ix.	Data Reporting	**I.**

Table 4: Existing System for Maternal Healthcare Information Exchange Assessment

Model	i	ii	iii	iv	v	vi	vii	viii	ix
ANC Booklet (Mother and Baby Book)	✓	✕	✕	✕	✓	✓	✕	✓	✓
Antenatal Care Register MOH 405	✓	✕	✓`	✕	✓	✓	✕	✓	✓
ANC Reporting Tool	✓	✕	✕	✕	✓	✓	✕	✓	✓

The current approach for the Maternal Healthcare exchange specifically the antenatal care process is still manual based where all pregnancy details must be recorded on the ANC Booklet (Mother and Baby Booklet) retained by a patient and the same information replicated on the Maternity Case Records in this case the Antenatal Care Register MOH 405. The antenatal record can also act as a referral letter if a patient is referred to the next level of care and thus acts as a link between the various levels of care as well as the antenatal clinic and the labor ward consequently ensuring early detection and management of treatable complications. The ANC Reporting tools (MOH 711 Form) forms the basis for compilation of required routine reports that is in turn entered on the DHIS2 to form a monthly report. The key assessed challenges identified from the analysis of the existing models indicated at table 4 above include:

i. Accuracy of Data Collected

Accuracy of data refers to the value of data stored for a specific object or records that are of true value. Based on the assessment Table 4, the current approach where nurses and health officials collect and collate maternal health information from mothers is manual and prone to errors especially due to fatigue and normal human errors. Thus, there are instances where maternal health data collected can be erroneous, stored erroneously and or come under erroneous translation when collating, transferring or consolidating.

ii. Continuity of Care

Continuity of care refers to the ability to maintain a constant and accountable relationship between a healthcare giver and a patient with a goal of providing management or service overtime. ANC Nurses face the challenge of retrieving past records to provide continuity of care to visiting or returning mothers either due to the sheer high numbers of mothers within the facility and the manual method of storage of records, which is cumbersome, ineffective and time consuming. Furthermore, this problem can be compounded when the mother decides to receive antenatal care services in a different facility, thus the ANC nurse cannot access the history register nor provide continuity of care. Those records become incomplete and maybe obsolete. This movement from one facility to another also makes it difficult for the hospital to do proper follow-up to the mother especially those whose conditions need proper guidance and monitoring. These compounds the challenge in the continuity of care as indicated on Table 4.

iii. Decentralization

Decentralization refers to the allocation of resources, data and information whereby multiple users can access, store and retrieve a copy of their data/resources for other users to access or replicate. The three booklets i.e., ANC Booklet (Mother and Baby Book), Antenatal Care Register MOH 405, ANC Reporting Tool are kept singularly within the hospital and in the possession of the mother thus, this data can only be accessed and reviewed singularly and manually when availed physically by any of the parties above. Thus, if a mother changes her health facility, previous health records stored in a different facility cannot be easily retrieved and reviewed as assessed from Table 4.

iv. Non-Repudiation

Non-repudiation is situation where an author or a source cannot deny or dispute the validity of their data or information. This challenge is encountered by the present method of handling maternal health data manually. It becoming difficult to ensure non-repudiation of antenatal activities performed. There is need to ensure the non-repudiation of all activities so as validity and transparency of data and information is maintained.

v. Immutability

Immutability is the aspect of information or data not being able to change or be modified. The current manual approach poses a great challenge in the collection, collation, consolidation and retrieval of data. Due to the sensitive nature of maternal health data, it is imperative that the information is immutable for retrieval and usage in future hospital visits as well as if the mother changes her health facility.

vi. Authentication

Authentication refers to the action of showing and verifying the identity of a user is true or genuine. The current manual approach lacks a robust and reliable approach of proving or presenting data and maternal health information as true, genuine, or valid. Authentication is critical in antenatal care since it involves the lives and wellbeing of both mother and unborn child.

vii. Redundancy

Redundancy refers to the ability to access and use the system, data and information even when one tenet of the system is faulty. Currently the manual system does not provide necessary and redundant testing and follow-ups especially when a mother's information is missing or difficult to retrieve when needed. This means that the system cannot provide a redundant back up nor be relied upon when and if the mother moves to a different health center, or when the mother misplaces the current antenatal care booklet.

viii. Data Stewardship

Data stewardship refers to the responsibility of ensuring the appropriate use of personal health data. Maternal Health Providers being the source of data they hold about mothers, have the obligation not to disclose confidential information. By conducting initial intake and converting the data in electronic form, they are thus obliged to disseminate the same to the patient or to other authorized individuals or organizations on request. The data steward in the current system cannot guarantee that disclosure will only be made to authorized individuals and cannot guarantee dissemination is done safely and securely.

ix. Data Reporting

This refers to the consolidation, collation, preparation and presentation of data from various transactions in an appropriate and presentable format and manner. Retrieval of documented data for reporting is so tasking as the process involves extracting information from the ANC register manually to a summarized ANC reporting form i.e. MOH 405 form which forms a basis of reporting to be entered on the DHRS2 system. This makes the current process extremely cumbersome and lengthy. In most cases, it is abandoned when the health center receives an overwhelming traffic of antenatal mothers seeking healthcare.

x. Auxiliary Challenges.

Given the fact that the hospital is a government facility and maternal care services are offered free, the numbers of mothers visiting the facility are high resulting to the nurses being overwhelmed in providing services through either clients misunderstanding the process and procedures and/or mothers moving to other facilities. In addition, mothers also lack proper awareness of the importance for a mother to visit the hospital for care. Some cases experience is mothers visiting the health centers way later on their pregnancy period, which gives the caregiver difficulties in doing proper assessment to the mothers. Lastly, due to the number of clients visiting the health centers, the waiting time for an individual to be seen by the care giver from the can be long resulting to the impatience of the client empathizing with the situation since data records takes time.

4.2. Design of the Maternal Health Information Exchange Model

This section presents the results of objective two of the study. This was achieved using the design process methodology. This sets out the design of the Maternal Health Information Exchange blockchain based Model followed the design thinking approach and methodology so as to help guide the conduct and suitability of the final product.

4.2.1. Design Recommendations Towards Implementing the Blockchain Based Model for Health Information Exchange in Maternal Healthcare.

The findings of the expert interview and discourse analysis discussed in objective 1 above, lead to the following design recommendations that should provide a solution to the challenges identified above:

i. The need to develop a solution that will enable and promote continuity of care for mothers within the ANC structure.
ii. There is need for provision of a secure maternal health care exchange system providing confidentiality, integrity and authenticity to patient’s information.
iii. Easy backup and retrieval of information within the hospital setup is vital as information can be gathered at ease.

4.2.2 Ideate through Brainstorming for Model Design.

This section presents the model design considerations through brainstorming and co-creation. This was achieved by consolidating the information created and gathered during the discourse analysis stage in the objective 1 above. The problems defined were analyzed through observations and further synthesized to define the core problems identified with antenatal care. Discourse Analysis followed the following steps.

4.2.3 Review Results and Draw Conclusions towards design

From the challenges taken up in the paragraphs above, several problems have been identified and analyzed to have an impact on the quality of antenatal care given to mothers and children. Lack of continuity in care affects early detection and management of treatable complications, which could affect the mortality of both mothers and children. The lack of continuity also affects proper follow-up to the mother proper guidance and monitoring, as issues discussed and provided for in past service visits are not conclusively dealt with. Further, mothers misunderstand the various process procedures thus force mothers to move to other facilities, seeking healthcare due to overcrowding or huge workload on the healthcare providers does affect continuity and general quality of healthcare.

It is also noted that the security, confidentiality and integrity of patient's information is critical. Not only does it assist in ensuring mothers are comfortable with the facility, but it reduces technology stigma and manages change. By moving from manual to automated systems, healthcare providers and their clients will avoid improper assessment and will reduce healthcare failures brought about by lack of understanding the importance of antenatal care. Another problem defined by this study is the poor retrieval of past records due to the summarized nature of reports on DHIS2. These summarized records lack details and specifics. To compound the current disposition, most healthcare providers are resistant to change yet the current systems in use cause dis-coordination. The fear of technology among the staff is simply because new systems are viewed as extra workload.

4.2.4 Ideate through Co-Creation for Model Design

The model was built with a view of aiding and supporting the ANC nurses and administrators facilitate exchange the data. The following perspective gives the requirement from both use cases.

a) IT Administrator

i. The system should provide security and confidentiality of Mother's data.
ii. The system should be accessible in a distributed manner to enable access to data and information from different health facilities.
iii. The system should be user friendly.
iv. Be able to support the users of the system.

b) Mothers

i. The Mother should offer personal and health information for storage on to the system.
ii. The mothers will be assigned an access code, which they should not share with unauthorized persons.
iii. The mothers will provide the access code when vising health facilities.

c) ANC Nurse

i. The nurses should be able enter mothers' records into the system correctly and appropriately within a specific visit.
ii. The nurses should retrieve information from the systems for purposes of continuity of care for the mothers.

d) Records Officer

The records officer should be able to access stored information at ease to improve summary of records for proper storage.

4.2.5 Mode of Operation.

The model will operate in the following processes.

i) Registration Process

A Mother visits a health facility and requests for an access code after registration and offering health information. The administrators enter her information and award the mother an access code.

ii) Use and Access Process

A fully registered mother should be able to access personal and health information from any health facility. They will do so by giving their secret code.

iii) Data Storage Process

The IT administrator should ensure that data is stored in a secure platform for access through applying a block-chain application and replication.

4.2.6 Model Design of a Secure Maternal Health Information Exchange using blockchain

The section presents results of design of the model from the brainstorming and co-creation discussed in the objective 2 above. Because of the discussions, the following model design was resultant, encompassing all factors identified in the brainstorming and discussed in the co-creation stage.

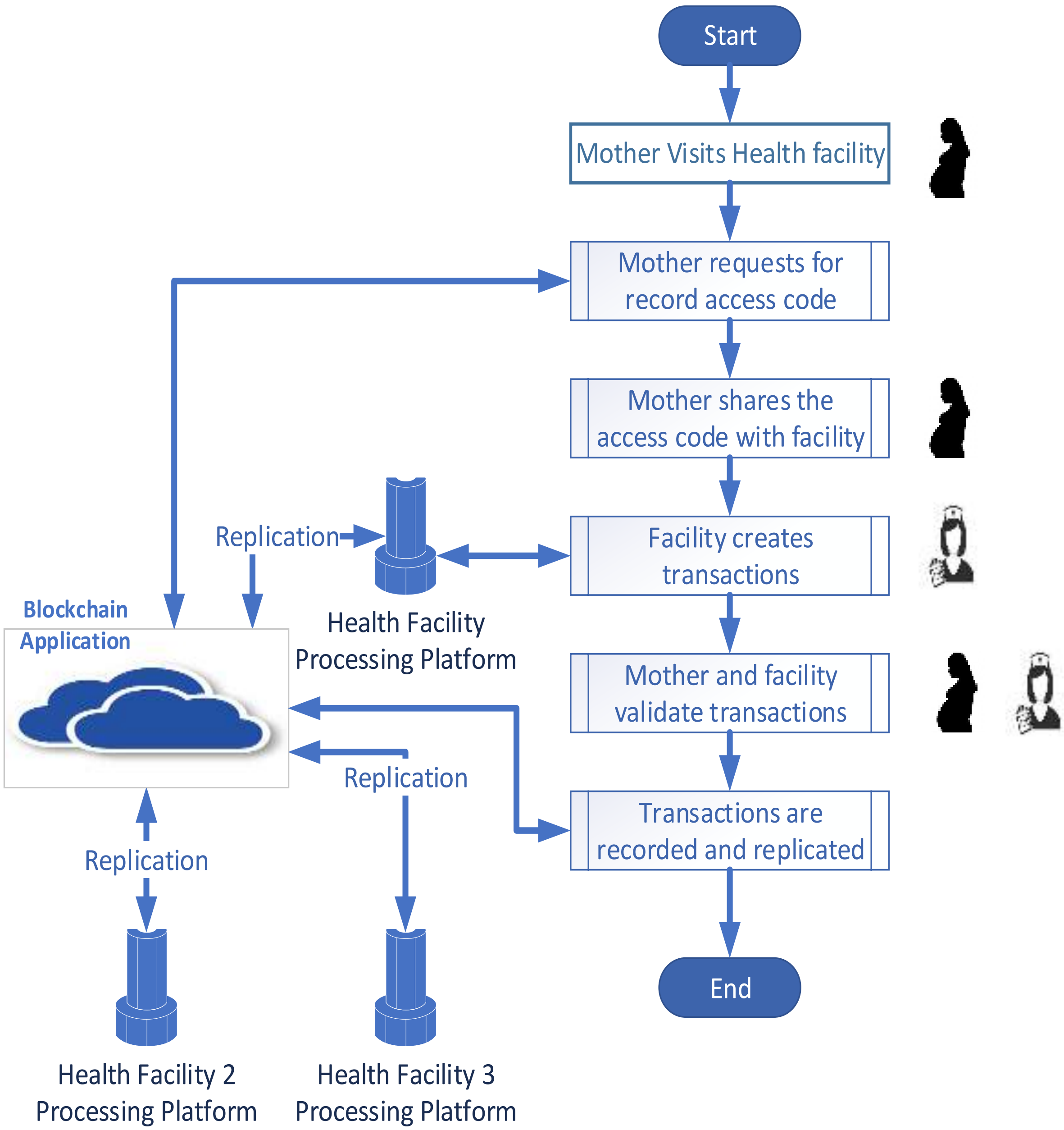


Figure 13: Model Design of a Secure Maternal Health Information Exchange Using Blockchain

4.2.7 Conclusion

The section discussed the design of the model following identification of the challenges encountered by various personnel within the provision of antenatal care at the current nature of maternal healthcare. The design thinking methodology was used to identify these challenges was achieved using literature review and expert interviews of the stakeholders within provision of maternal healthcare. The results of this section above aided in designing of the model.

Finally, the model guided in the implementation of the model as espoused in the following chapter 4.3.

4.3 Model Development and Implementation

This model was implemented using rapid prototyping. The approach involves creation of low-fidelity object for testing a concept. The model development was achieved and its results described in the chapters below.

4.3.1 Model Rapid Prototype Results

This section presents the results of the rapid prototyping, which was employed in collaboration with a nested rapid prototyping methodology within the design thinking methodology of research. The following were the steps implemented to achieve the model.

a. Requirements for the Maternal Health Information Exchange Model

This step was achieved through empathizing by employing expert interviews approach, from the key stakeholders as espoused in the sub-chapter 4.2.1. The results of this step were used in the next model design step sub-chapter 4.3.2.

b. The Model development and implementation

The model was designed to be implemented using the Ethereum platform, which was used in the designing of the Blockchain Nodes. These nodes within the Maternal Health Information exchange model operate based on a private blockchain platform with an application-programming interface (APIs) which enable exchange of data securely. The model's Admin and User Interface were designed to enable multiple users on the platform health facility to access and allow the replication of data.

c. Prototype Development Steps

The prototype development followed the following steps.

i) Environment Setup.

The environment required an Ethereum Blockchain node, which was a physical server, connected to the internet. The Ethereum software exposed a port locally to pair with other nodes on the internet, in this case, the private hospital blockchain network with select nodes allowed to join the network. The blockchain nodes had the following on the hospital network:

- An end user, a computer or phone having Ethereum client software (Meta Mask) used to access the blockchain network.

- Smart contracts are pushed to the network and are immediately accessed from any node. This then forms the basis of shared ledger and all information is available to all hospitals. The smart contracts were used to control access and organize interactions between different hospitals and patients.
- A web interface that communicates with the blockchain network hosted online independently with the use of an API to communicate with the network.
- A library used for interaction with the API is called web3 provider, which controlled the format and exchange of data and pushing new information to the actual network.
- To cover for the proof-of-concept basis. A selected Node was elevated to approve transactions (creation of new health records)

The resultant model is show in Figure 14, indicating the various hospitals and their basic contacts.

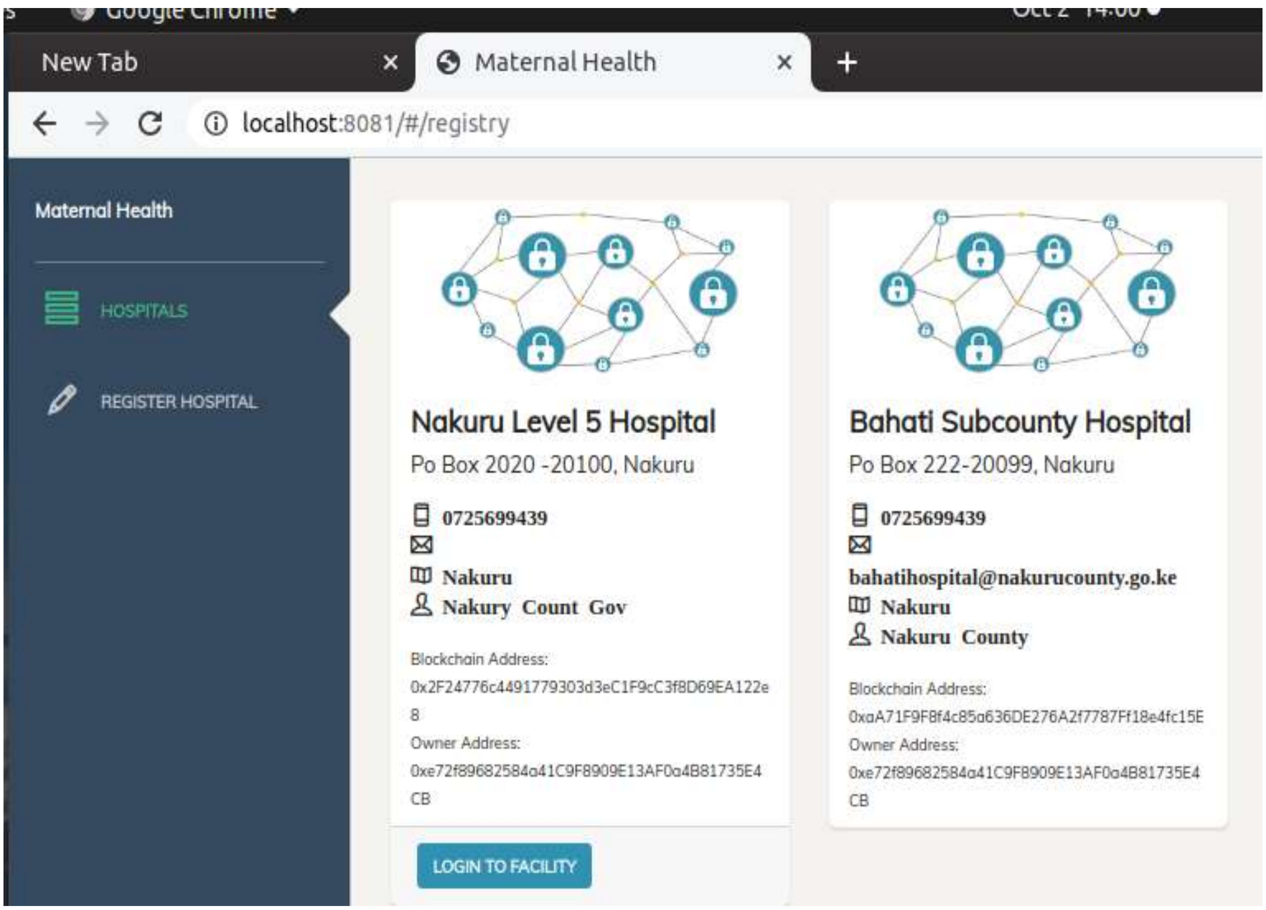


Figure 14: Roll of Hospitals with a Virtual Blockchain on the Enumerator

The first step involves the patient registering for a virtual secure account on the model through either of the hospital with a virtual blockchain account on the model. General personal information is collected and fed into the system and the patient is given a secure password, which will be used to access the model. The code executed to form the sub-model is presented in Appendix B Code Listing A. The line 16 of appendix B code listing A below enables registration at a particular hospital;

```
<div class="col-md-6 col-xl-3" v-for="(i, j) in [1,2,3,4]" :key="i">
<img src="@/assets/img/facility_default.png" alt="...">
<h4>Kabarak University Hospital {{j+1}}</h4>
```

The code above results into a sub-model that enables capture of critical patient data and registration of the same into a virtual block. Figure 15 shows the registration panel on the model.

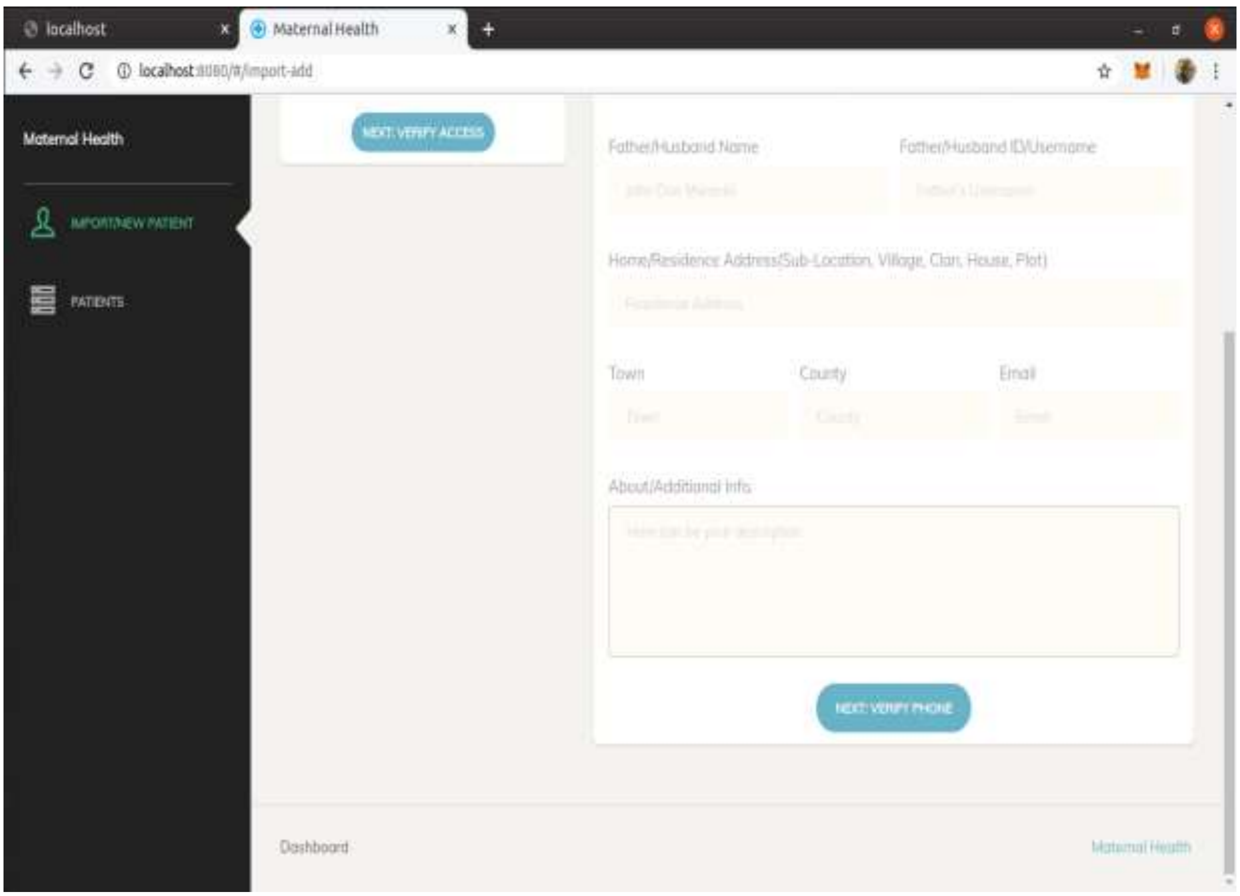


Figure 15: Patient Data Capture Section on the Model

As per the model design elucidated in chapter 4.2, a patient is at liberty to move from one institution to another based on convenience and/or family relocation due to work or other reasons. Therefore, a smart contract that facilities the transfer of digital assets between parties under the agreed-upon stipulations or terms in a blockchain platform can be transferred to another entity. The model achieved this by adding truffle config file (truffle.js.) which will connect ethereum node running on local host and then creating a contract (counter. Sol) which will define the Event, the variable and the methods in use. Thereafter, a deployment script is added and named as ‘2_initial_migration.js for Counter.Sol. If a patient so wishes to access her smart contract from another hospital, she can import her data by submitting unique information to another facility in the model. She only knows this unique information. The code executed to form this particular sub-model is presented in Appendix B Code Listing B. The line 16 of appendix B code listing B is shown below;

```
Import/add patients
verifyPhone(){
this.verify_phone = !this.verify_phone;},
searchPatient(){
this.requesting_access = !this.requesting_access;},
proceedSearch(){
//this.$router.push({path: '/patients'})
```

The code above results into a sub-model that enables import of critical patient from another previous hospital to the current facility. The information can only be imported on a patient’s volition and using the patients’ unique code only known to the patient. Figure 16 below shows the patient import of data process from another previous hospital to the current facility on the model.

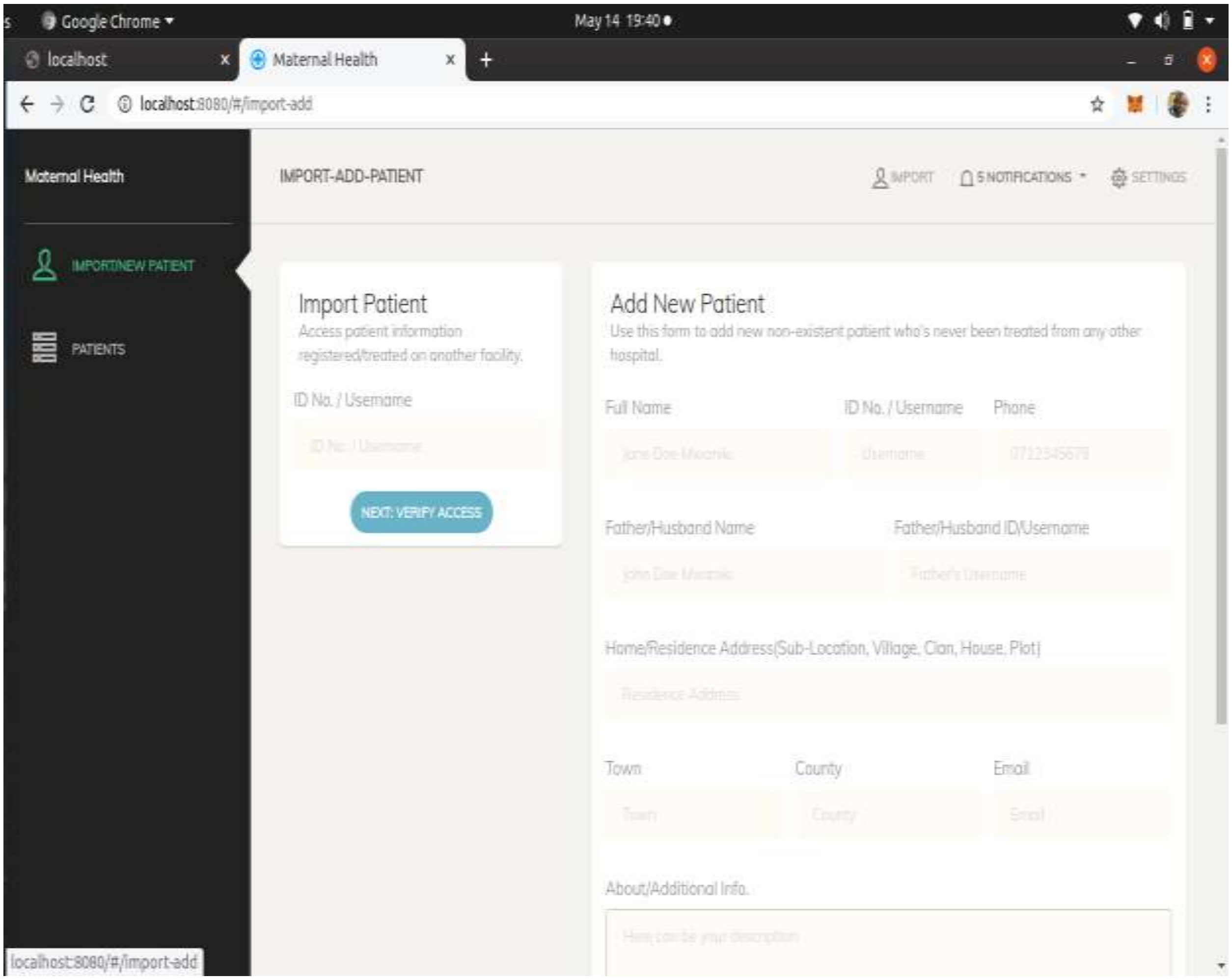


Figure 16: Import of Patient's Data from The Previous Hospital into Another Facility Using a Unique Code

Once a patient has been successfully registered or transferred their personal data to a facility, the resultant data can be viewed on the model securely and is only visible on demand by the healthcare workers. The code executed to form this aspect in the model is presented in Appendix B Code Listing C. The line 16 of appendix B code listing C is shown below;

```
PaperTable},
data() {
return {
handbook:{
preventive_services: {
columns: ['Service', 'Date', "Next Visit"],
data:[
```

The code above enables the querying of blocks to query for information using counter.js source file for purposes of displaying this data for health workers consumption. Figure 17 shows the patient data recorded at the current or previous facility on the model.

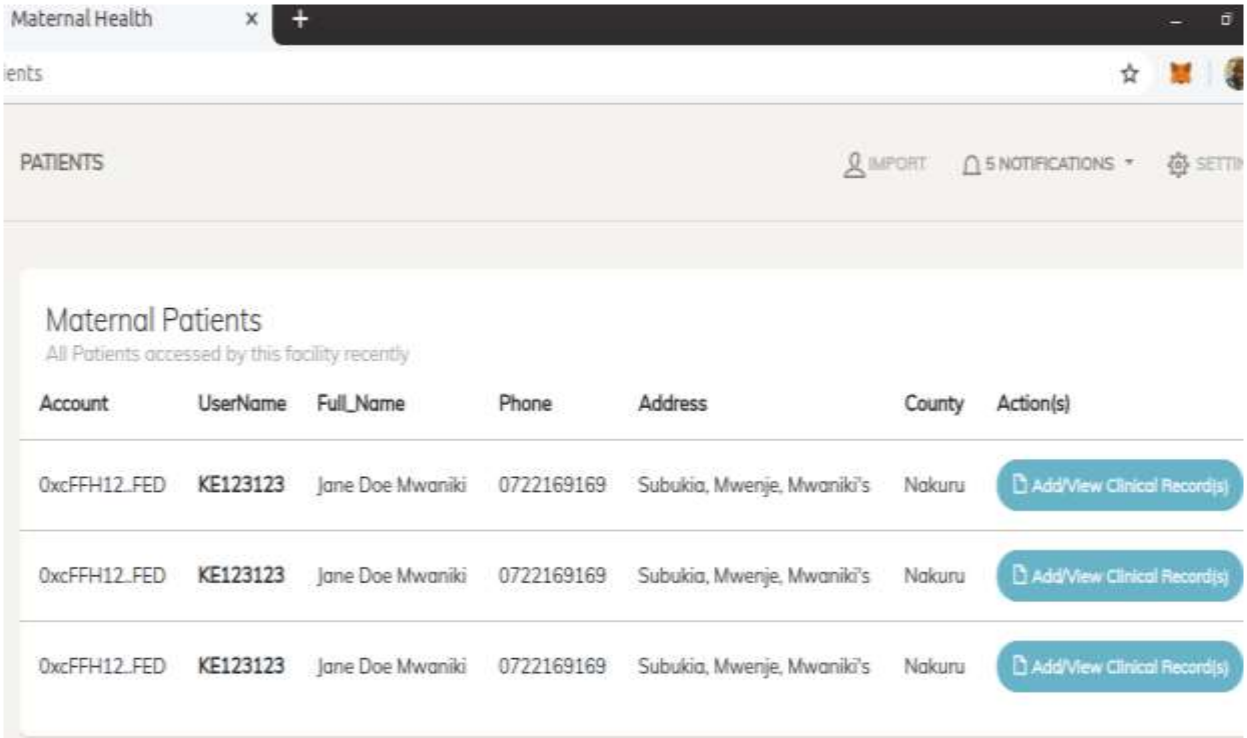


Figure 17: Maternal Patients Register

In addition, the health worker has the ability to add more information and/or data into the maternal patients register. This sub-model displays relevant patient's bio data, but does not contain any healthcare records. This health-related record is captured in a separate register in the following chapter.

The health facility can also access a summary of all maternal patients within the facility captured by the model. This enables the management or IT administrator to have a summary of data on total number of patients, and their various transactions done on the facility. This can be for purposes of contacting the patient, preparing reports and administrative purposes.

Figure 18 shows the various patient accounts as viewed by administrators of the health facility on the model.

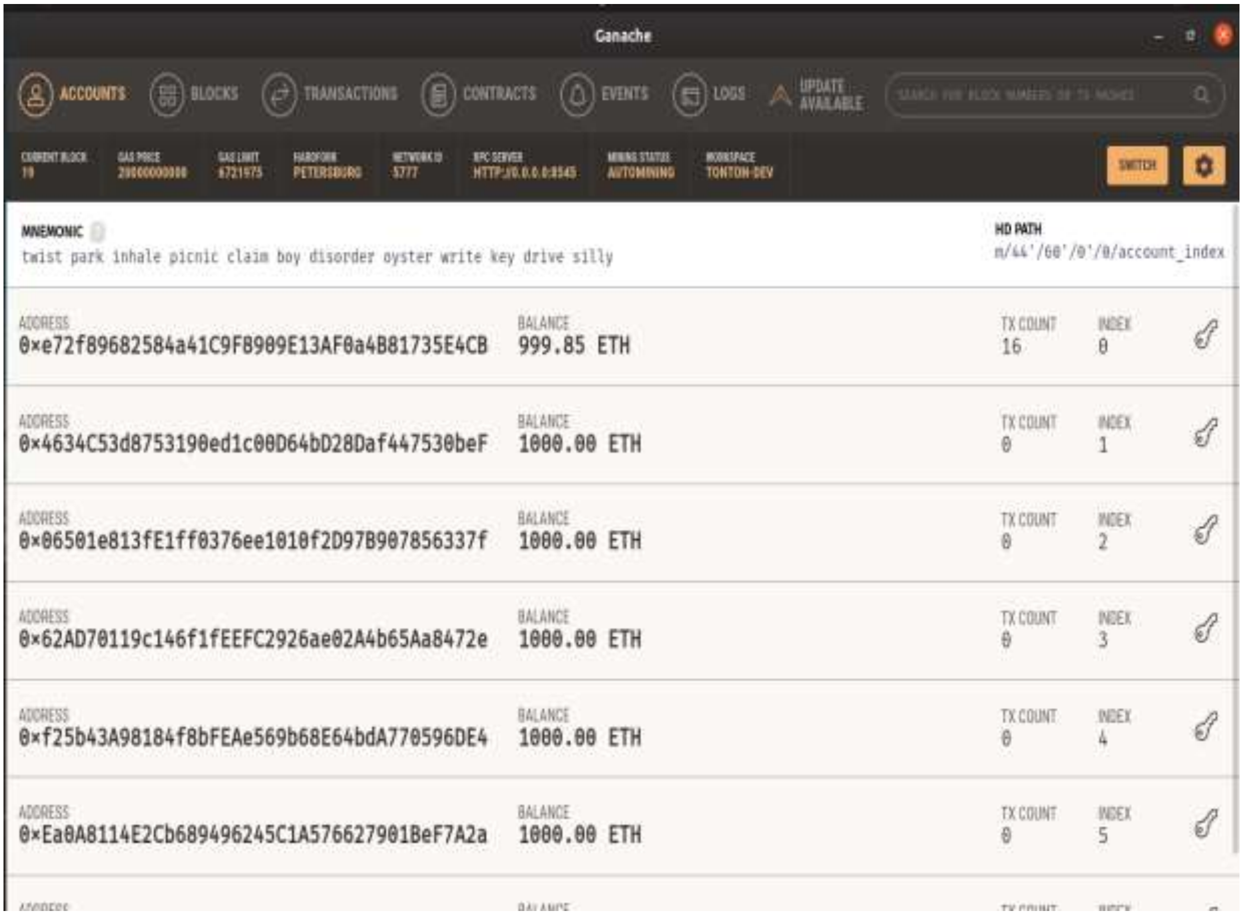


Figure 18: Patients Accounts on the Model with Their Encrypted Addresses

The model also accommodates all the smart contracts for various hospitals. These can be accessed through the Metamask wallet on the Ethereum blockchain accessed through Mist. The Figure 19 displays in summary the smart contracts within the model.

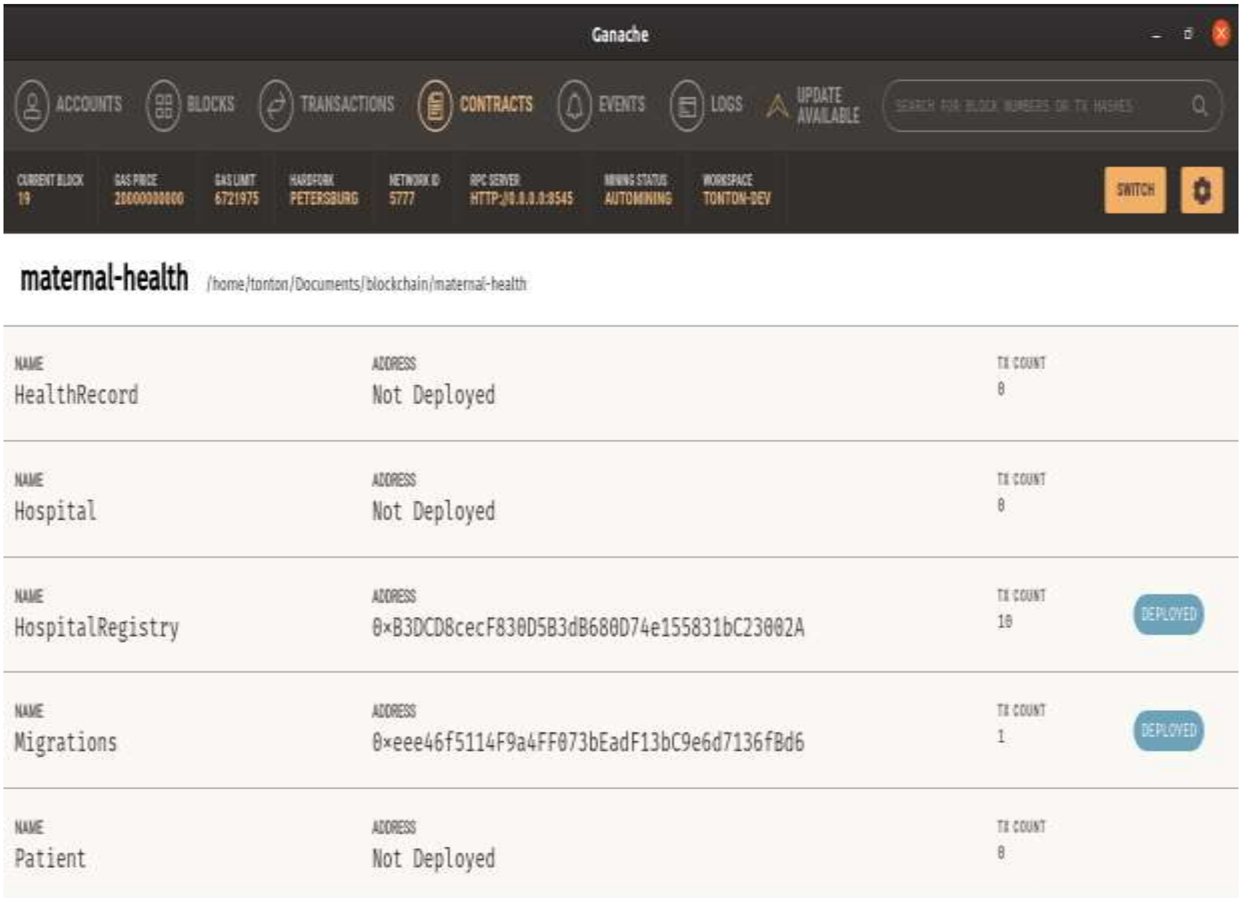


Figure 19: Smart Contracts on the Maternal Health Information Exchange Model

One of the critical use cases of the model is to record relevant maternal processes during the antenatal care sessions. This includes clinical notes and physical body examination by the healthcare worker e.g., blood pressure, height and weight, breasts examination, abdomen examination, vaginal and vaginal discharge examination, preventive services e.g., malaria and tetanus, medical and surgical history. Drug allergies are also recorded as well as previous pregnancies history if any. The sections are broken into the following segments;

a) Maternal Profile
b) Medical and Surgical History
c) Previous Pregnancy
d) Physical Examination
e) Antenatal Profile
f) Infant Feeding (infant feeding counseling and exclusive breastfeeding)
g) Present Pregnancy Table
h) Weight Gain chart

i) Preventive Service

The above forms were integrated into the model for purposes of capturing the above patient health care records. The code executed to form this aspect in the model is presented in Appendix B Code Listing D. The line 16 of appendix B code listing D is shown below

```
Import { Card } from "@/components/index";
Export default { components: { Card, },
Data () { return { patient: {},
Search: { username: ""},
requesting_access:false,
verify_phone: false
```

Because of the above code, the model produces various antenatal forms for purposes of recording mother healthcare records. Figure 20 shows the medical and surgical history.

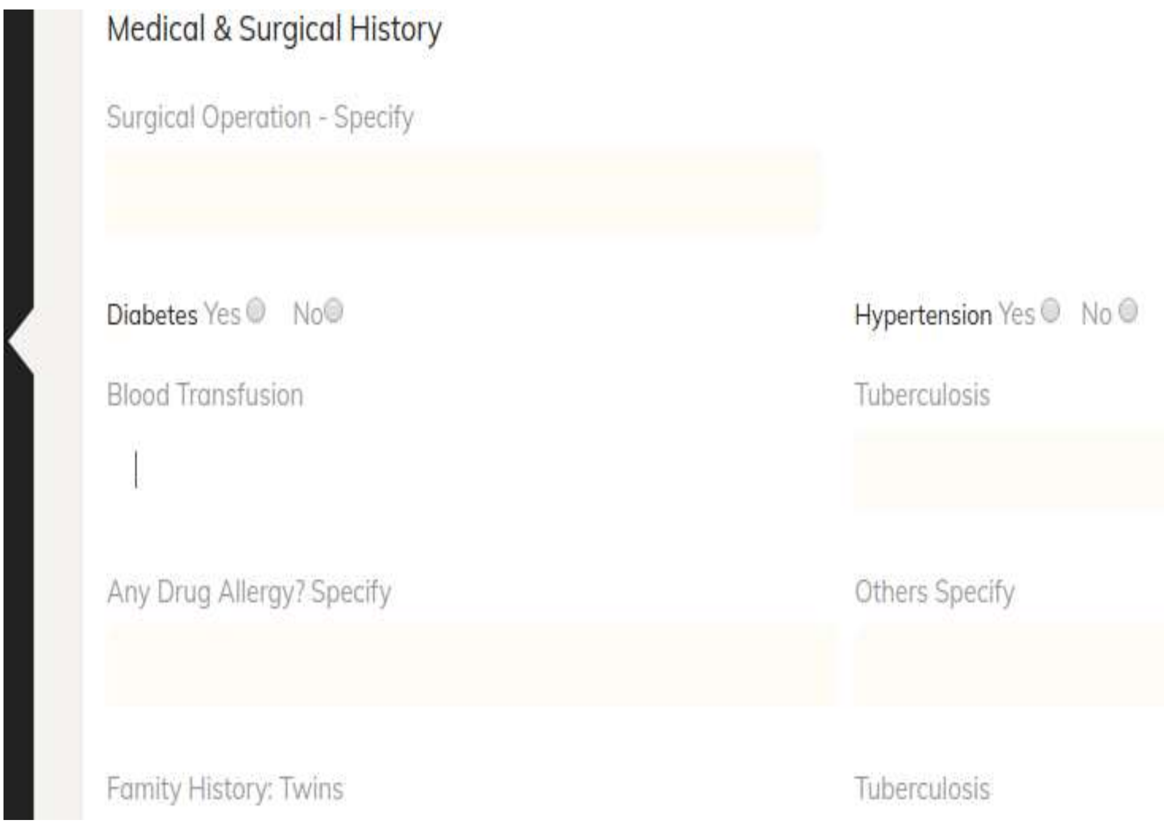


Figure 20: Mothers Medical and Surgical History.

In addition, Figure 21 shows the previous pregnancy table. Data from previous pregnancy can inform the current condition and aid in taking better care of the mother and child.

Previous Pregnancy

Pregnancy Order	Year	Number of Times ANC attended	Place of Delivery	Maturity	Duration of Labor	Type of Delivery	Birth weight	Sex	Outcome	Puerperium	Actions
											+

Figure 21: Previous Pregnancy Form

Further, the current pregnancy information is also recorded. Figure 22 shows the present pregnancy table. Data from present pregnancy shows the current condition and informs the health care provider on best way to give care to the mother and child.

Present Pregnancy Table

No of visits	Date	Urine	Weight	Bp	Hb	Pallor	Maturity	Fundal Height	Presentation	Lie	Foetal Heart	Foetal Movt	Next Visit

Figure 22: Present Pregnancy Table

4.4 Prototype Testing and Evaluation

This section presents the results of prototype testing and evaluation of the model for purposes of appraising and determining if the model was successful. The prototype was evaluated whether it met the objectives and thus its achievement using the goals-based evaluation methodology. This methodology is used to evaluate the outcome of a project against the objectives and or goals set out at the beginning. An evaluation test regime was used to perform the model evaluation for purposes of determining whether it is fit-for-purpose and if it met its desired goals.

4.4.1 Prototype Testing and Evaluation of Suitability of Model

The following are the key tenets to evaluate in our model blockchain prototype against the existing system used in the maternal health information exchange. Through a demonstration to the IT personnel and the ANC nurse, the process verified and evaluated the model to ascertaining how the model overcomes the weaknesses of the existing system.

a) Test Scenario 1: Accuracy of Data

This Test Scenario tested and evaluated the ability of the model to capture and store information on maternal health accurately and without errors. This was to test the ability to collect data, stored, translation and retrieve the same without errors when collating, transferring or consolidating.

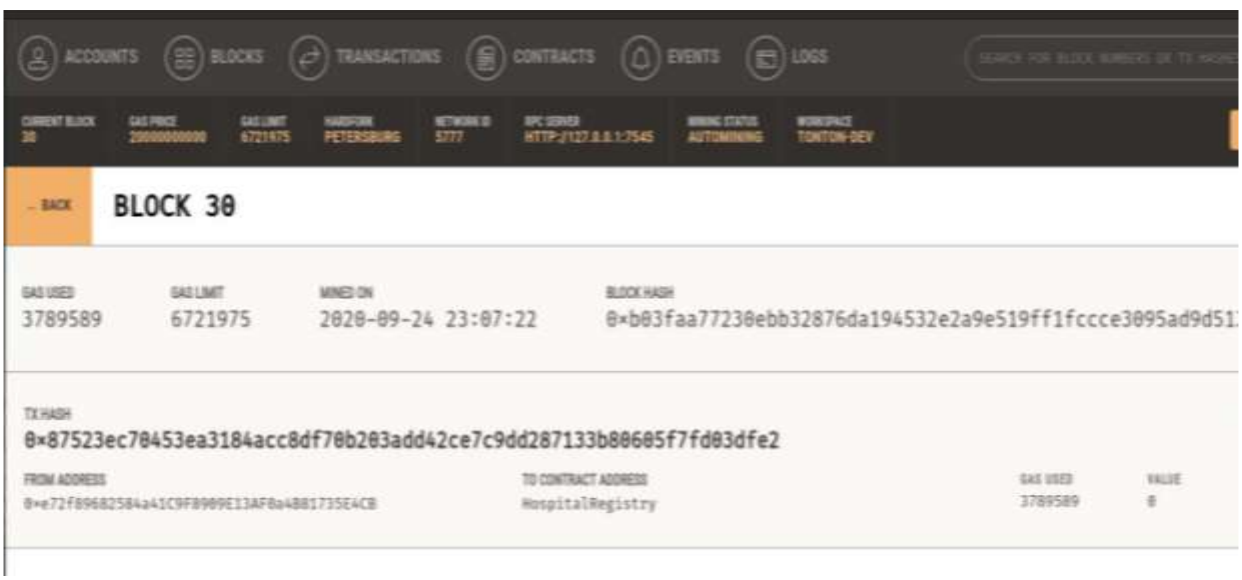


Figure 23: Data Translation and Retrieval on the Model

The figure 23 displays how data is retrieved and translated into and from encoded encryption to ensure accuracy and integrity of health information stored by the model.

b) Test Scenario 2: Continuity of Care

This Test scenario seeks to evaluate whether the challenge of retrieving a mothers health records to visiting or returning mothers from other health institutions can be successfully. Continuity of Care is impended when a mother moves from one facility to another making it difficult for the hospital to do proper follow-up to the mother especially those whose conditions need proper guidan4e and monitoring. The figure 23 shows that the protype has ability to provide continuity of care when a mother for example moves from Nakuru level five hospital to Bahati sub-county hospital they able to access ANC information exchange.

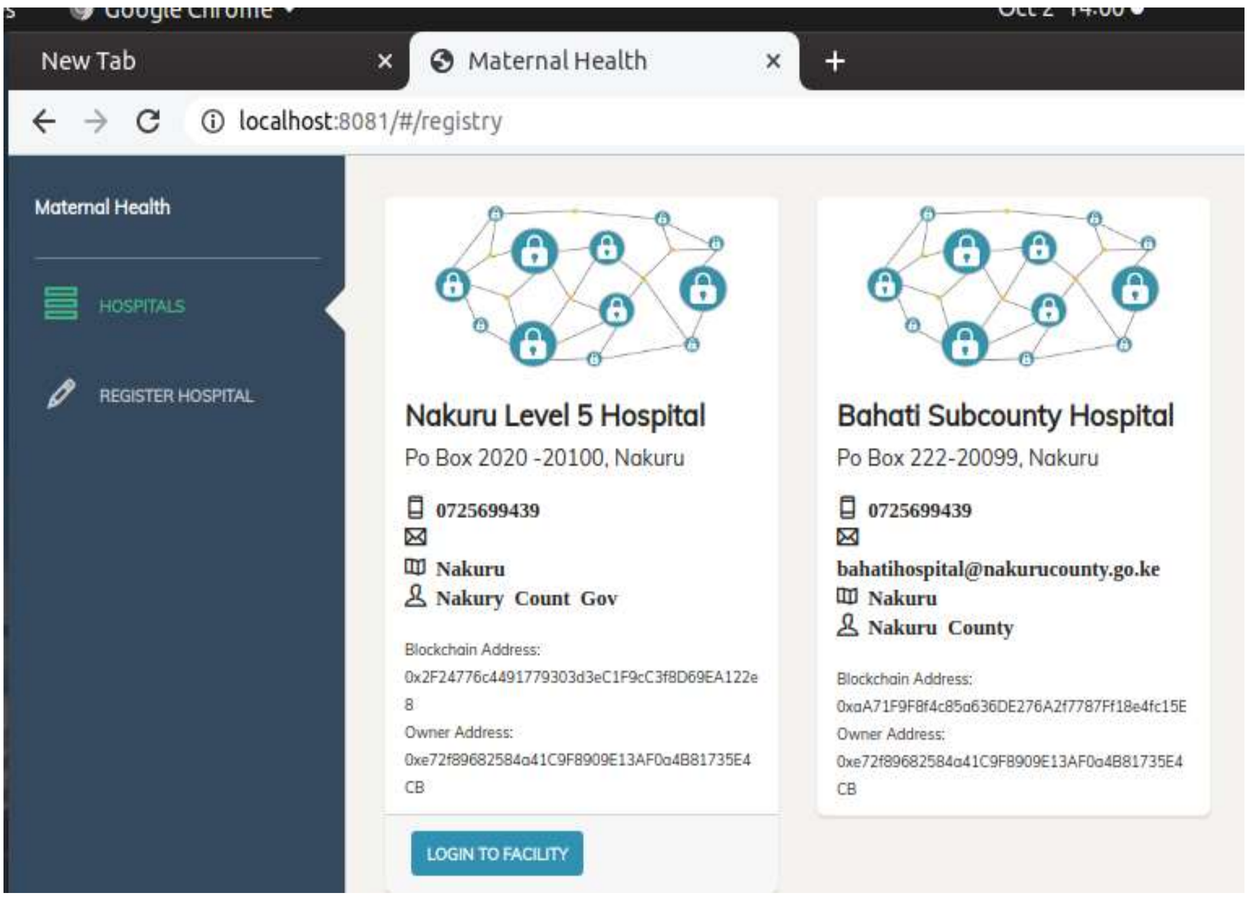


Figure 24: Continuity of Care Indicating Different Hospitals Which Can Access a Visiting Mother's Health Data.

The figure shows a number of healthcare institutions which can share data with authority from a mother, thus ensuring that if a mother seeking health services from a different institution, can access the same data once authority is given thus ensuring that a mother receives continuity of care.

c) Test Scenario 3: Decentralization

The current approach has three booklets i.e., ANC Booklet (Mother and Baby Book), Antenatal Care Register MOH 405 and the ANC Reporting Tool which are kept singularly within the hospital and in the possession of the mother thus, this data can only be accessed and reviewed singularly and manually when availed physically by any of the parties above. The prototype however has the ability to provide decentralized storage and dissemination of the same data using the blockchain model. Figure 25 shows the ability to provide decentralization within the model.

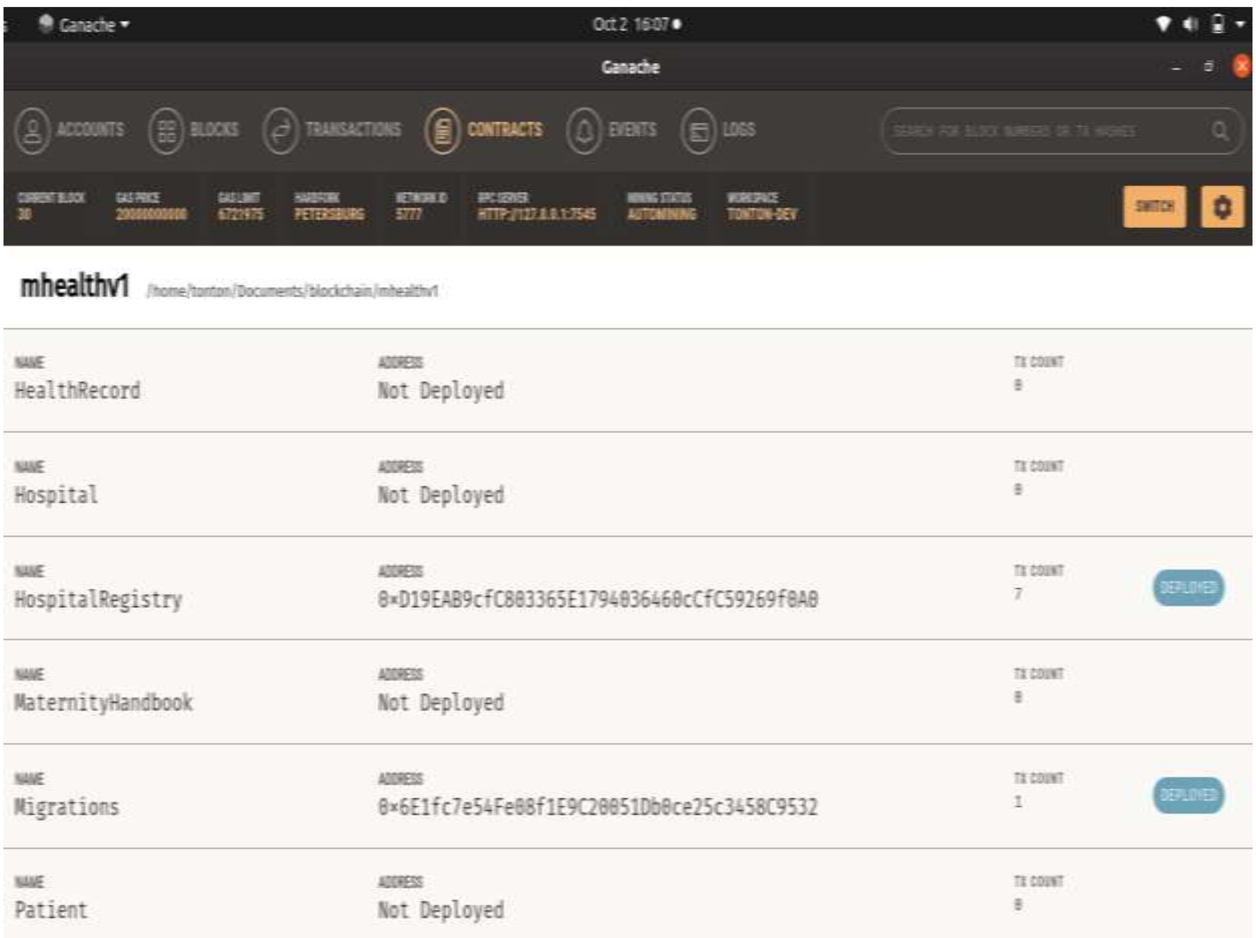


Figure 25: Decentralization Feature on The Model for Maternal Health Information Exchange.

The figure displays the decentralization feature, which enables different hospitals to access and exchange health information for purposes of enabling service delivery as well as sharing intelligence and analysis of various critical health information.

d) Test Scenario 4: Non-Repudiation of Data and Events on the Prototype

This Test scenario tested the assurance that there was non-repudiation of all activities achieved and ensures validity and transparency of data and information is maintained. The prototype was able to achieve non-repudiation of data and events. Figure 26 below shows the non-repudiation of data and activities on the model.

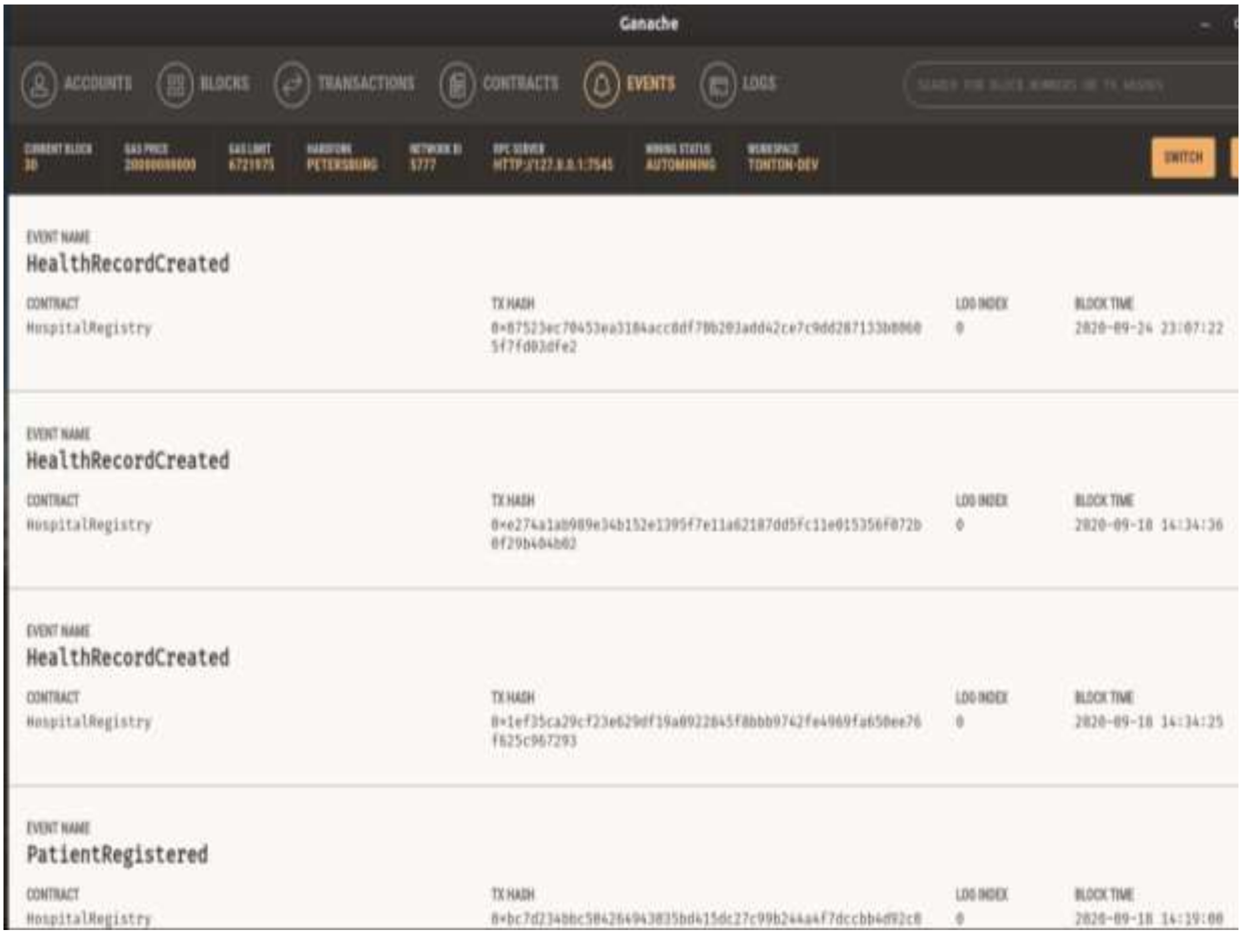


Figure 26: Non-Repudiation of Data and Activities

This feature enables and ensures that any action taken on the model cannot be refuted or denied in future. Thus, mothers and health providers' records and data are kept with utmost integrity.

e) Test Scenario 5: Immutability

The prototype was able to prove immutability and show that the various actions and information is immutable for retrieval and usage in future hospital visits as well as if the mother changes her health facility. The unchangeability aspect of the system was indicated when the health worker had an option of just updating data from what was entered during the mother's previous visit with the same facility or a different facility.

f) Test Scenario 6: Authentication of Users

This Test scenario proves the prototype provides a robust and reliable approach of proving or presenting data and maternal health information as true, genuine, or valid. Authentication is critical in antenatal care to ensure only those users authorized to view data, do so. The working prototype here uses a two-step authentication method to ensure and affirm identity of the user(s) through an SMS gateway which submits a message containing a temporary expiring code which is a one-time password (OTP), fed into the dialogue box. This feature enables the user to authenticate herself ensuring that only the authorized users can access and update their accounts.

Figure 27 shows the one-time password (OTP) messaging as received from the SMS gateway.

Figure 27: The One-Time Password Verification Code Sent On SMS

The figure 27 shows the various auto-generated OTP sent to users' phone. The correct OTP once fed into the system and enables the admin to progress towards updating the mothers' records.

Blockchain applications are known for robustness and steadiness even when huge amounts of traffic and requests are experienced. The figure above shows how robust the model is even when receiving multiple requests.

g) Test Scenario 7: Redundancy

Currently the manual system does not provide necessary and redundant testing and follow-ups especially when a mother's information is missing or difficult to retrieve when needed. The prototype was tested to show ability to provide a redundant back-up that can be relied upon when and if the mother moves to a different health center, or when the mother misplaces the current antenatal care booklet. Figure 28 shows redundancy capabilities of the model.

Figure 28: Redundancy Abilities of The Model

The figure 28 shows the ability to retrieve information from a backup reliably specially to mitigate cases of lost or damaged books mostly by mothers.

h) Test Scenario 8: Data Stewardship

This prototype was able to guarantee that disclosure will only be made to authorized individuals and proved to guarantee dissemination can be done safely and securely through a blockchain model. The figure 29 shows data stewardship abilities of the model.

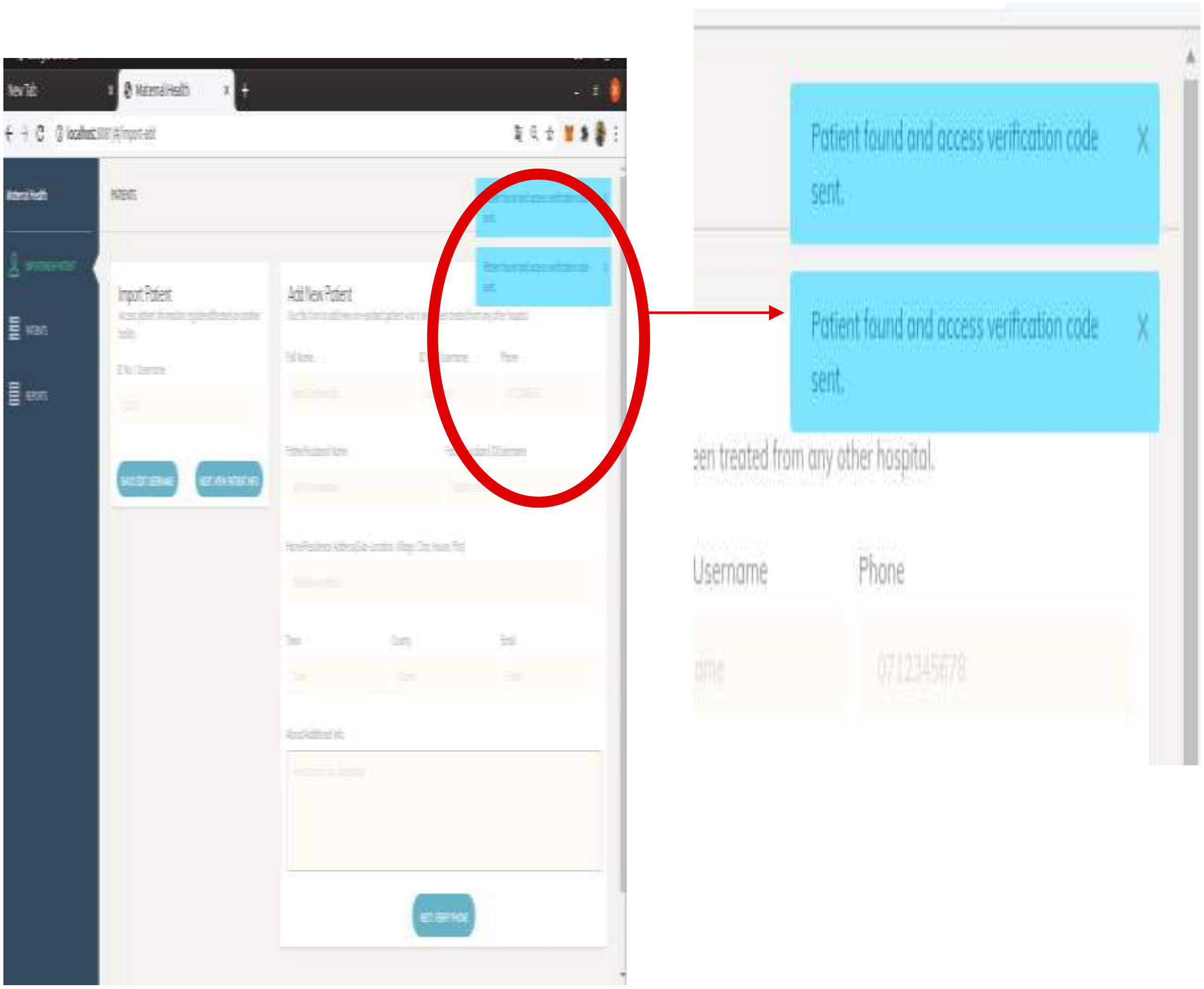


Figure 29: Data Stewardship Ability of The Model

The model has exemplary abilities in providing the ability of data stewardship by ensuring only authorized users access the health data.

i) Test Scenario 9: Data Reporting

The blockchain model was able to adopt the ANC reporting tool MOH 711 form, which is the actual form used to provide monthly summary report of the ANC Clinic and later fed on the DHIRS2. The figure 30 shows data reporting abilities of the model.

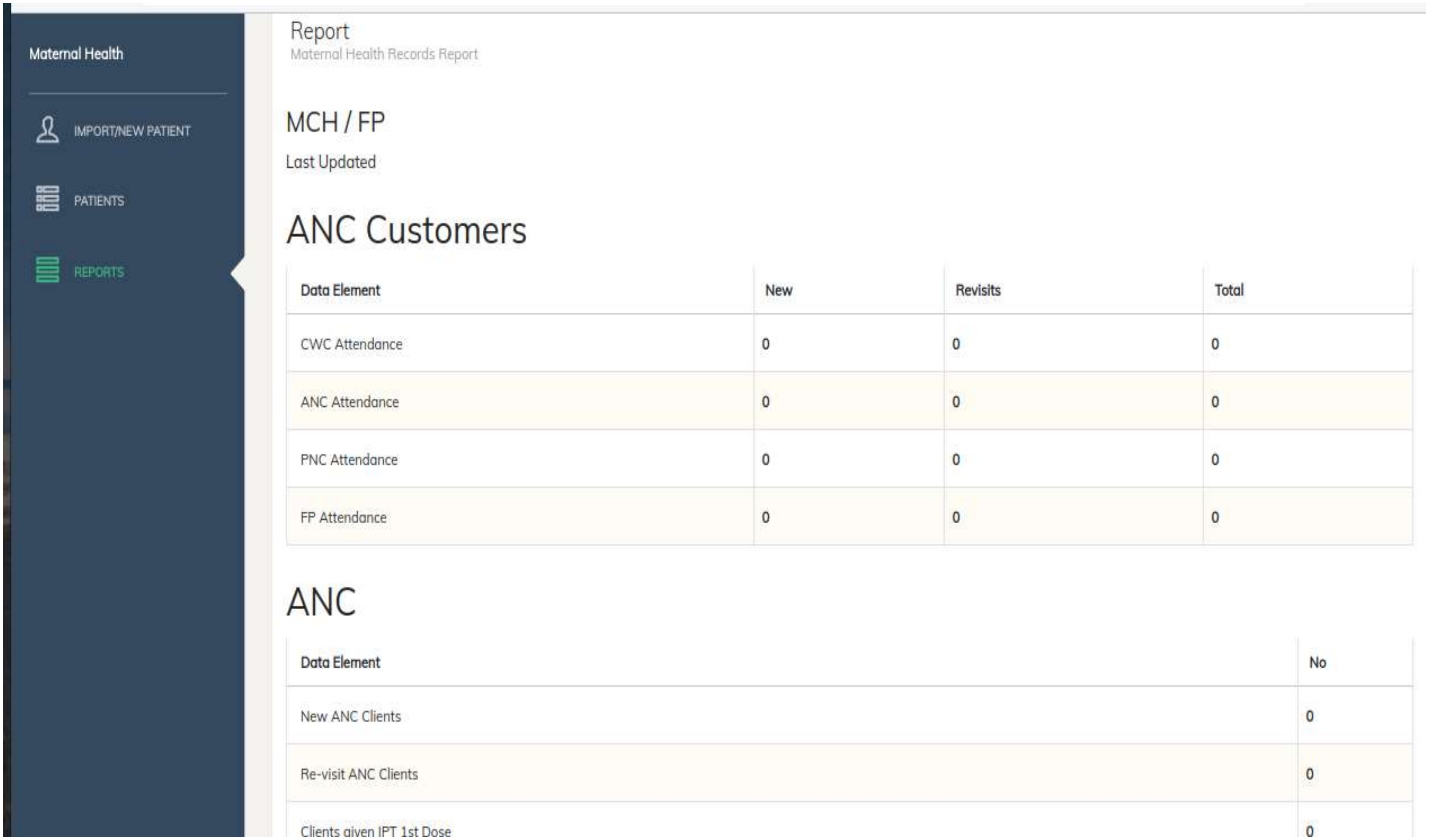


Figure 30: Data Reporting Tool

4.5 Prototype Validation

Prototype validation was conducted through an expert survey. Fifteen experts participated in the survey to validation based on the variable discussed in the section 4.1 to give a significant validity of the use within the ANC domain. Out of the 16 experts who participated in the validation process 12 experts accurately responded to the feedback form provided during the validation process.

The following were the results of the validation process.

4.5.1 Validation of the model Variables

a) Accuracy of Data collected

From the responses 69% (11 respondents, SA=7 & A=4) agreed and 6.25% (1 respondent, NS=1) not sure that the model had the capability of capturing and storing information accurately based on the information gathered from the mother visiting the facility. Using the rule of majority, it indicates that the model may be considered valid.

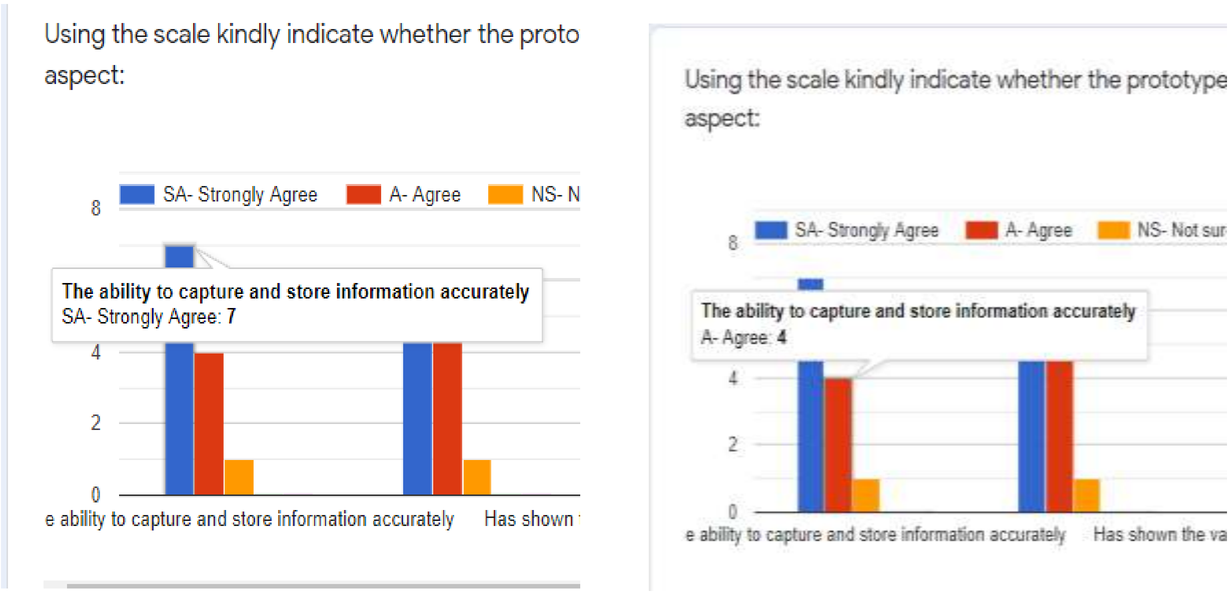
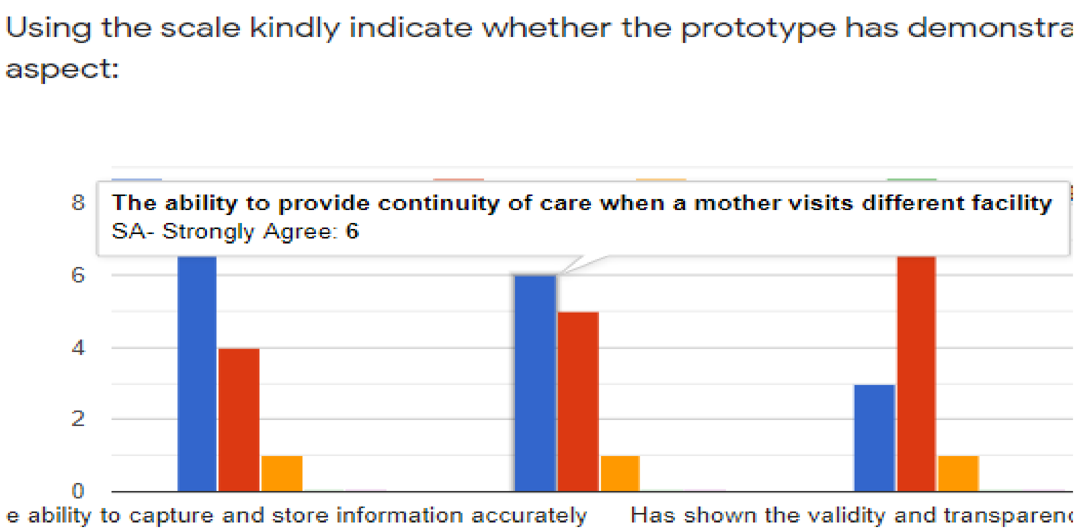


Figure 31: Accuracy of Data Variable Response

b) Continuity of Care

From the responses 69% (11 respondents, SA=6 & A=5) agreed and 6.25% (1 respondent, NS=1) that the model had the ability to provide continuity of care when a mother visits different facility. Using the rule of majority who agreed to this variable, it indicates that the model may be considered valid as it will provide the continuity of care aspect for the mother within different facilities.



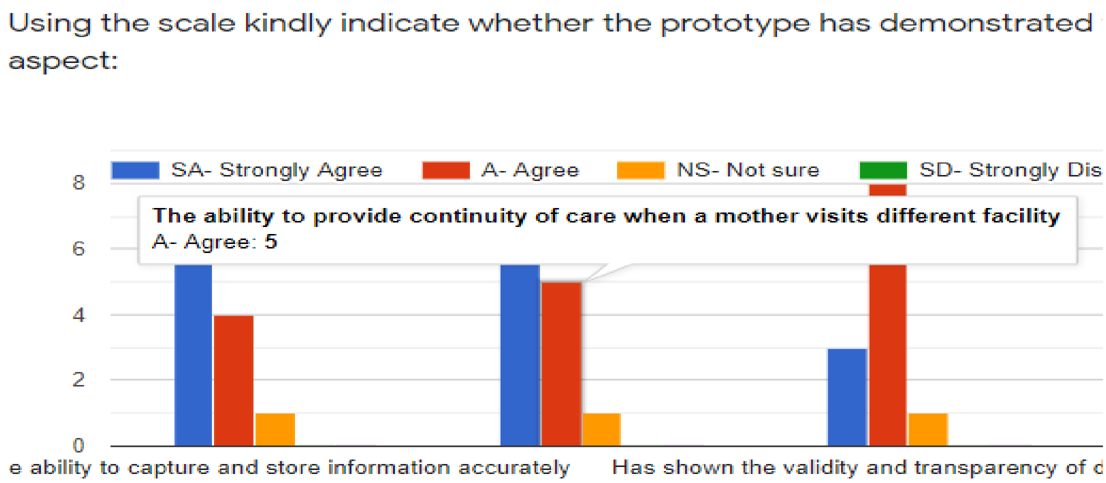


Figure 32: Continuity of Care Variable Response

c) Decentralization

From the responses 69% (11 respondents, SA=3 & A=8) agreed and 6.25% (1 respondent, NS=1) that the model has shown the aspect validity and transparency of data collected. Using the rule of majority who agreed to this variable, it indicates that the model may be considered valid.

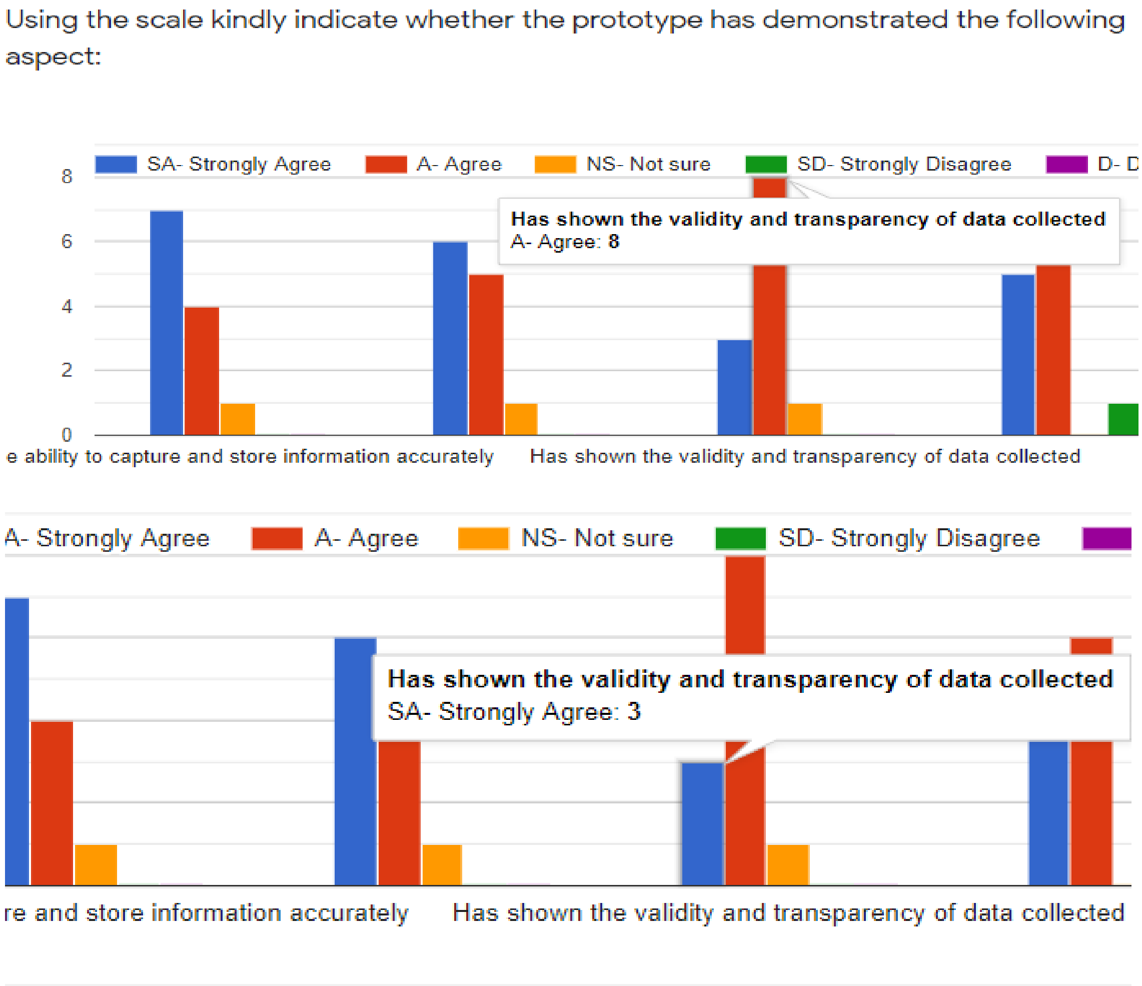


Figure 33: Decentralization Variable Response

d) Non-Repudiation and Immutability

From the responses 69% (11 respondents, SA=5 & A=6) agreed and 6.25% (1 respondent, SD=1) that the model has shown that an author or a source cannot deny or dispute the validity of the data or information and the data entered cannot be changed or be modified. Using the rule of majority who agreed to this variable, it indicates that the model may be considered valid.

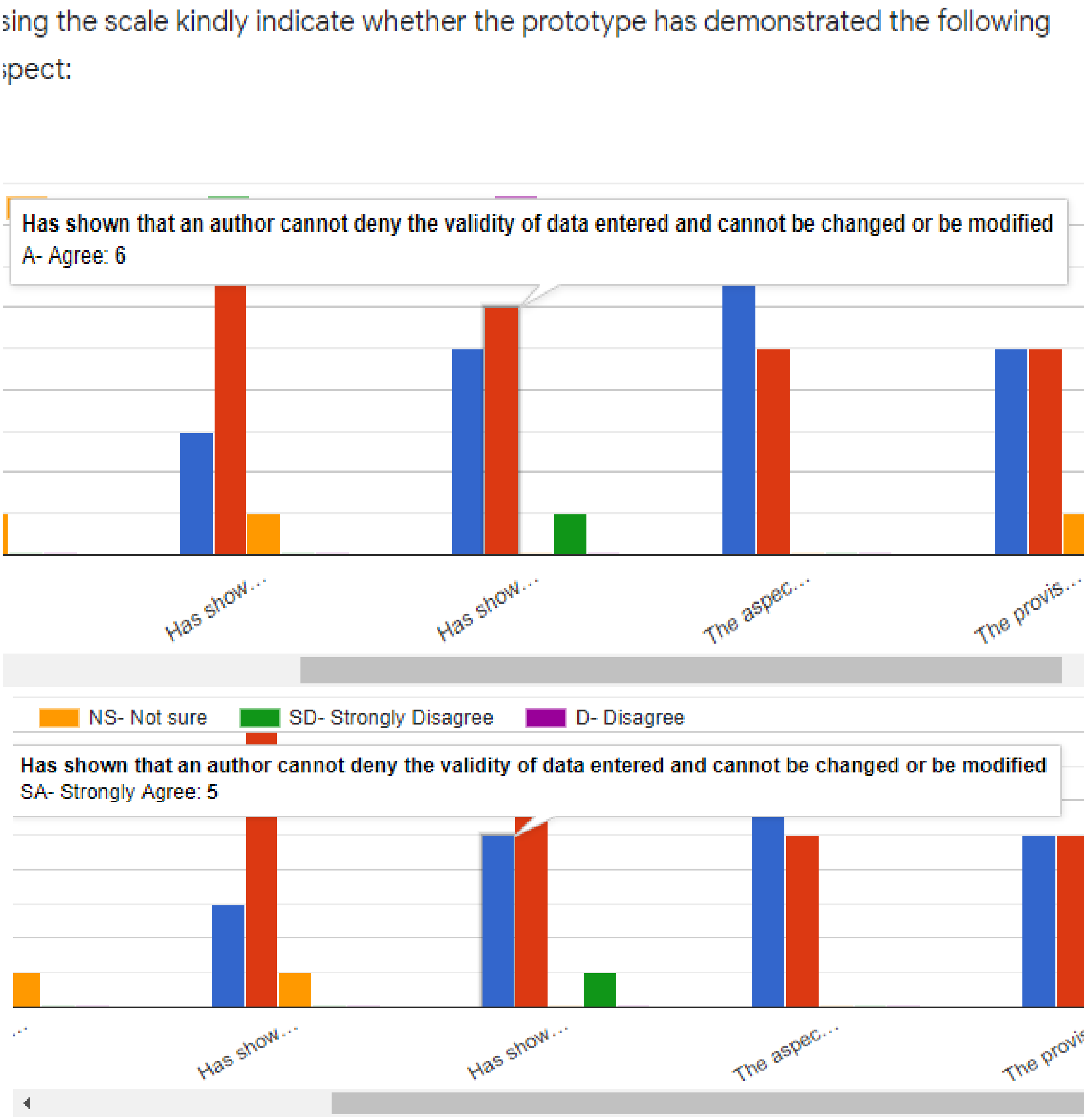


Figure 34: Non-Repudiation and Immutability Variable Response

e) Authentication

From the responses 75% (11 respondents, SA=7 & A=5) agreed that the model has shown that only authorized users and owners of the data can access the model. Using the rule of majority who agreed to this variable, it indicates that the model may be considered valid.

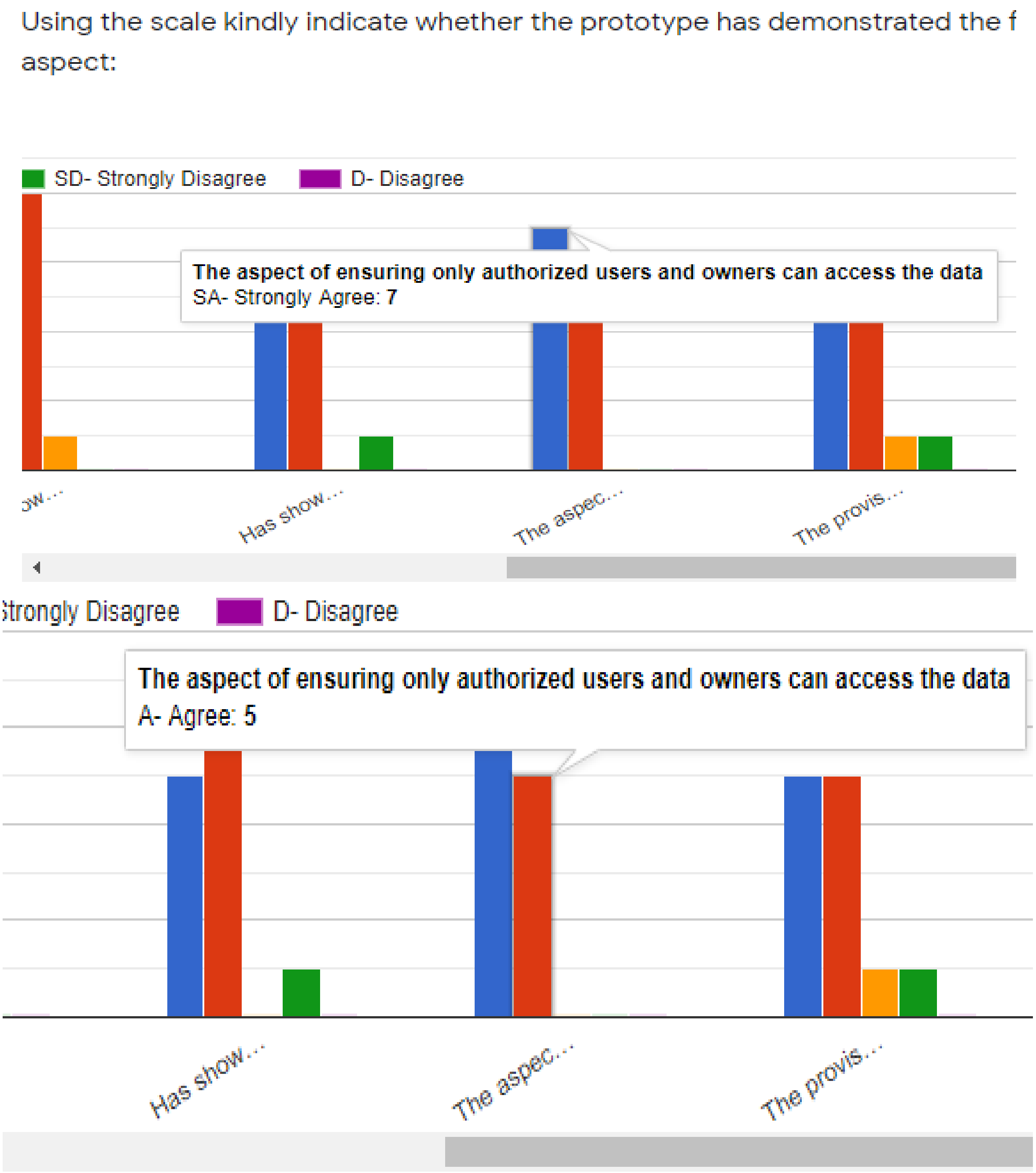


Figure 35: Authentication Variable Response

f) Redundancy and Data Stewardship

From the responses 62.5% (10 respondents, SA=5 & A=5) agreed , 6.25% (1 respondent, NS=1) and 6.25% (1 respondent, D=1) that the model has shown the aspect provision of a redundant back-up and data retrieval in case of data loss. Using the rule of majority who agreed to this variable, it indicates that the model may be considered valid.

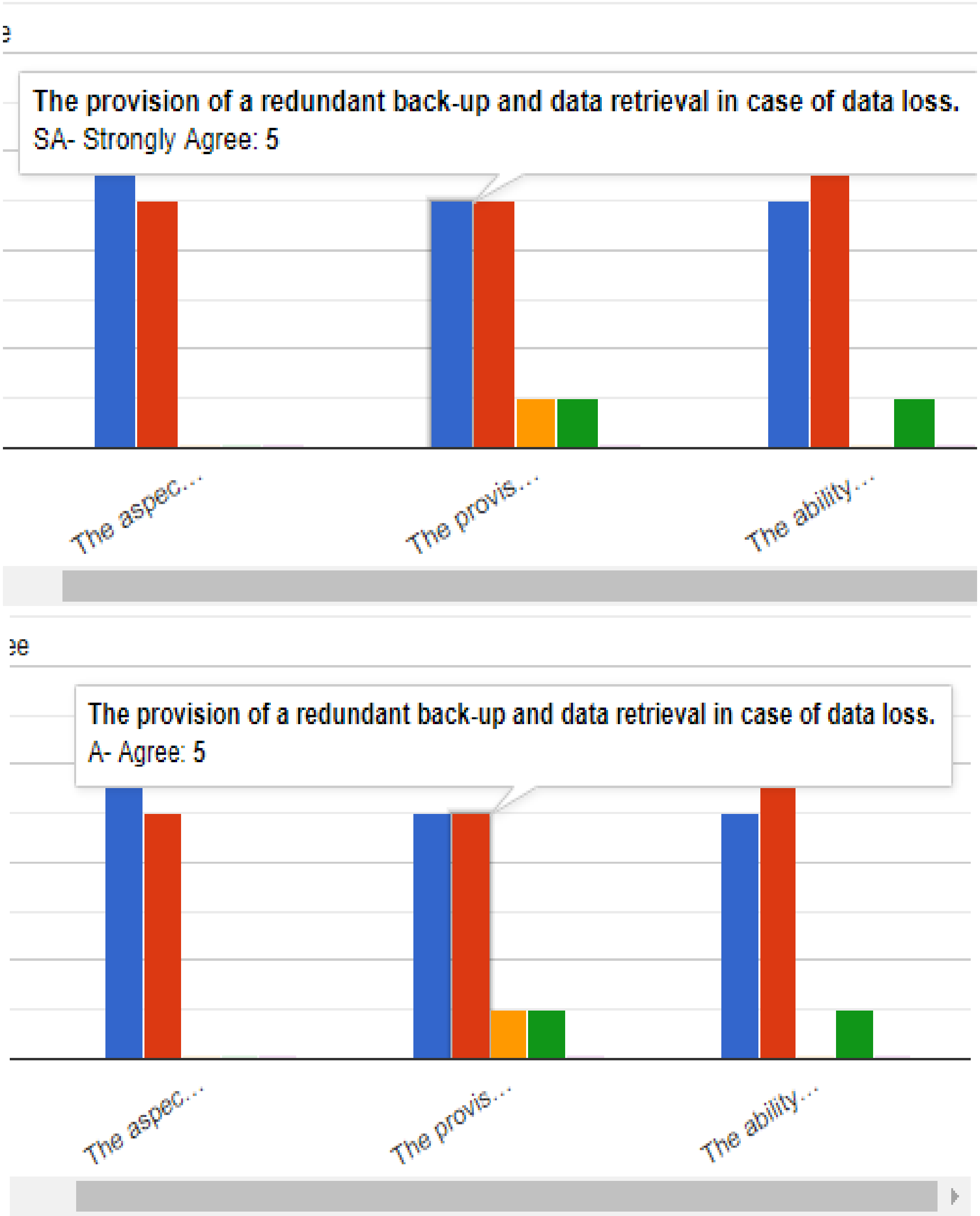


Figure 36: Redundancy and Data Stewardship Variable Response

g) Data Reporting

From the responses 69% (11 respondents, SA=5 & A=6) agreed and 6.25% (1 respondent, NS=1) that the model has the ability of providing a summary of data collected for the entire period of time for storage, reporting and forecasting within the hospital setup. Using the rule of majority who agreed to this variable, it indicates that the model may be considered valid.

Figure 37: Data Reporting Variable Response

4.6 Conclusion

The chapter above discussed the the challenges and design of Health Information Exchange in Maternal Healthcare. Further, this chapter looked into implementation of the blockchain based model for Health Information Exchange in Maternal Healthcare. In addition, the chapter discussed evaluation and the validation of the suitability of the blockchain based model for Health Information Exchange in Maternal Healthcare focusing on security, functionality, usability, interoperability, reliability, cost-effectiveness, and performance.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter provides conclusion and recommendations on the research on the maternal health information exchange model design, development, evaluation and results. It also provides further areas of study.

5.1 Summary

This study was guided by the weaknesses of the current method of maternal health information exchange within the antenatal health care process in Kenya. The study gives an outcome that blockchain technology which is yet to be implemented with all its advantages can be a solution to the maternal health information exchange.

5.2 Conclusions

This section presents the conclusions made from the research as per the specific objectives. The conclusions in this study with regard to each of the objectives are presented in this section and they are summarized as follows:

5.2.1 Determine the challenges of Health Information Exchange in Maternal Healthcare.

Research Question 1: What are the challenges of Health Information Exchange in Maternal Healthcare?

With regards to this objective, the study evaluated various challenges that inhibit the current health information exchange system that is in use. To achieve this, various secondary data was studied using literature review and primary data was achieved using expert interviews. This brought about the consummation of various challenges and weaknesses of the status quo. The current disposition does not allow continuation of data collection for use, since it prevents continuity of care when mothers move from one location to another. Incomplete and inconsistency of data collection, inaccurate and unreliable reports, records redundancy, data inaccessibility, missing data in the records due to regular oversight, and data being difficult to read as records grow so large over time. In addition, the process is tedious and difficult to extract data from it for clinical research and reporting in health centers.

5.2.2 Design of a blockchain based model for Health Information Exchange in Maternal Healthcare.

Research Question 2: How can a Health Information blockchain model for maternal exchange be designed?

The results of objective 1 guided the design of the model, whose recommendations were put in place when designing the resultant model. The results showed that there is a need to develop a solution that will enable and promote continuity of care for mothers within the ANC structure. Further, there's need for provision of a secure maternal health care exchange system providing confidentiality, integrity and authenticity to patients' information. There is also need to provide easy backup and retrieval of information within the hospital setup is vital as information can be gathered at ease. The research espoused the need for training and awareness for staffing officers within healthcare centers.

The design process also used the brainstorming and co-creation method, which in turn gave the perspective of the various functional requirements for the model use cases. The model design output was as per the system flow on Figure 13.

5.2.3 Implementation of the blockchain based model for Health Information Exchange in Maternal Healthcare.

Research Question 3: How can a Health Information blockchain model for maternal exchange be implemented?

With regards to this study, objective three sought to implement the blockchain based model for Health Information Exchange in Maternal Healthcare. The model was developed and implemented using rapid prototyping whose approach involves creation of low-fidelity object for the purpose of testing a concept. A registration module was developed to allow the new addition of a health facility within the blockchain network. The module also included the patient registration profile where patient's details are captured. The registered patients' details captured can also be accessed from in a different facility through a smart contract that facilitates the transfer digital assets between parties under a consensus as indicated on section 4.3.1. To ensure exchange of data and continuity of care for the mother from one health facility, a sub-module was added to allow data being shared across the platform. A summary of all ANC mothers can also be generated from the model as shown in Figure 32; this provides the aspect of better and ease of extraction and data reporting. The entire code of the developed model is presented in Appendix I.

5.2.4 Evaluation of the suitability of the blockchain based model for Health Information Exchange in Maternal Healthcare.

Research Question 4: How can the suitability of a blockchain based model for Health Information Exchange in Maternal Healthcare be evaluated?

This objective discussed the results of model testing and evaluation for the purposes of appraising and determining if the model was successful. The model was evaluated whether it met the objectives and thus its achievement using the Goals-based evaluation methodology. This methodology was used to evaluate the outcome of a project against the objectives and or goals set out.

An evaluation test regime was used to perform the model evaluation after a demonstration was done to the IT personnel and the ANC Nurse, for purposes of determining whether it is fit-for-purpose and if it met its desired goals. This process also verified and evaluated the model for the purposes of ascertaining how the model overcomes the weaknesses of the existing system. The model was verified based on the set evaluation criteria from the existing model's evaluation which included: Accuracy of Data collected, Continuity of Care, Decentralization, Non-Repudiation, Immutability, Authentication, Robustness, Redundancy, Data Stewardship, and Data Reporting as shown in the Key of Assessment Criteria in section 4.1.1 Table 3 and Table 4.

5.3 Recommendations

The Kenyan government should look at re-evaluating the current ICT policy to include use of more ICT solutions especially blockchain for provision of a secure, open, reliable, and interoperable system. The current ICT policy 2019, does not factor in blockchain as an essential tool for provision of healthcare services, specifically maternal health. There is need as well, to ease bureaucracy within healthcare systems in Kenya, with a view of reducing time taken in procurement of ICT the services, equipment and human resource thus, speed up the absorption of bleeding edge technology in healthcare provision.

5.3.1 Policy Recommendations

The National Information, Communications and Technology (ICT) Policy 2019 provide a legal framework and technical support for blockchain to securely record all transactions. The Distributed Ledgers Technology and Artificial Intelligence Taskforce though the ministry of ICT recommends a framework to be develop the use of DLT for patient data, data on nutrition and registration of births and deaths. The Kenya health policy 2014-2030 provides a guide to Plan, design and install ICT infrastructure and software for the management and delivery of care which will facilitate proper use of ICTs.

5.3.2 Recommendation for Further Research

Blockchain technology is continuously developing at a faster rate in various sector of the society. Much progress has been made within the period this thesis was completed, and a variety of research groups and firms have begun to form solutions with the use of blockchain. This Study had a number of limitations including the provision of blockchain systems to hold large amount of data, expertise to design and develop real use case models, among others. Recommendations for research integration of blockchain model applications for purposes of providing data exchange in the areas of health such postnatal, family planning follow-ups, outpatients sections and specialists consultation clinics within the field of health.

Given that this study adopted a qualitative research design, there’s is need to implore further study using quantitative methods of the test scenarios to establish the statistical significance of the improvement in the secure exchange of data.

REFERENCES

Abate, T. M., Salgedo, W. B., & Bayou, N. B. (2015). Evaluation of the quality of antenatal care (ANC) service at higher 2 health center in Jimma, south west Ethiopia. OALib, 02(04), 1-9. doi: 10.4236/oalib.1101398

Agha, S., & Tappis, H. (2016). The timing of antenatal care initiation and the content of care in Sindh, Pakistan. . BMC Pregnancy and Childbirth, 16.

Agrawal, G. (2019). Top Libraries For Ethereum Smart Contract Developers. Retrieved 2019, from medium.com:https://medium.com/quiknode/top-libraries-for-ethereum-smart-contract-developer-60168aba6f6

Andoni, I. S. (2018). *Blockchain As An Application Platform*. Retrieved 12 2018, 28, from Forbes:https://www.forbes.com/sites/forbestechcouncil/2018/05/07/blockchain-as-an-application-platform/#39933b65576e

Athenahealth. (2018). *True Interoperability | Knowledge Hub*. Retrieved 01 10, 2019, from athenahealth:https://www.athenahealth.com/knowledgehub/interoperability/intraoperability-vs-interoperability

Attwell, G. (2006). *Evaluating e-learning. A guide to the evaluation of e-learning.* California, USA: Evaluate Europe Handbook Series Volume 2.

Azaña, A. (2018). A complete guide to building Ethereum DApps with MetaMask. Retrieved from:https://medium.com/crowdbotics/building-ethereum-dapps-with-meta-mask-9bd0685dfd57

Azaria, A., Ekblaw, A., Vieira, T., & Lippman, A. (2016). *A Case Study for Blockchain in Healthcare:* “MedRec” prototype for electronic health records and medical research data. *IEEE* .

Ballantyne, A., & Rogers, W. A. (2016). *Pregnancy, vulnerability, and the risk of exploitation in clinical research.* In F. Baylis, & A. Ballantyne (Eds.), Clinical Research Involving Pregnant Women (139-159). (Research ethics forum; 3). Springer, Springer Nature. https://doi.org/10.1007/978-3-319-26512-4_8

Barratt, H., & Shantikumar, S. (2018). *Methods of sampling from a population*. Retrieved March 30, 2021, from https://www.healthknowledge.org.uk/public-health-textbook/research-methods/1a-epidemiology/methods-of-sampling-population

Beltran-Aroca, C. M. (2016). Confidentiality breaches in clinical practice: what happens in hospitals. *BMC Medical Ethics*, 17(1), 52.

Bidgoli, H. (2018). Successful Integration of Information Technology in Healthcare: Guides for Managers. *Journal of Strategic Innovation & Sustainability, 3*, 13.

Bigchain, D. B. (2018). *The Blockchain Database.* Berlin, Germany: BigchainDB 2.0 .

Bmz.de. (2014, 04 13). *Kenyan innovation wins e-Health award*. Retrieved from Federal Ministry for Economic Cooperation and Development: https://health.bmz.de/what_we_do/Health-systems/health_information_systems/Kenya-innovation/index.jsp

Bowman S. (2013). Impact of electronic health record systems on information integrity: quality and safety implications. Perspectives in health information management, 10(Fall), 1c.

Buterin, V. (2018). *On Public and Private Blockchain*. Retrieved from Ethereum Blog: https://blog.ethereum.org/2015/08/07/on-public-and-private-blockchains/

Carcary, M. (2011). Design Science Research: The Case of the IT Capability Maturity Framework (IT CMF). *The Electronic Journal of Business Research Methods*, 109-118.

Care (ANC) Service at Higher 2 Health Center in Jimma, South West Ethiopia. Open Access Library Journal, 2(04), 1.

Chao, C. (2016).The impact of electronic health records on collaborative work routines: A narrative network analysis. *Journal of Medical Informatics*, 94, 100–111.

Chawani, M. S. (2014). A Cross-case Analysis of the Effects of EMR Deployment on Antenatal Care Services in Rural Health Centres in Malawi. *Journal of Health Informatics in Africa*, 2(1). https://doi.org/10.12856/JHIA-2014-v2-i1-89

Christian Catalini, J. S. (2017). Some Simple Economics of the Blockchain. *MIT Sloan Research Paper*, 32.

Corten, P. A. (2018). Blockchain Technology for Governmental Services: Dilemmas in the Application of Design Principles. *51st Hawaii International Conference on System Sciences*, 10.

Cronholm, S., & Goldkuhl, G. (2003). Strategies for information systems evaluation-six generic types. *Electronic Journal of Information Systems Evaluation*, 65-74.

Deloitte. (2018). *2018 Global health care outlook: The evolution of smart health care.* U.K: Deloitte.

Don, & Tapscott, A. (2018). What is Blockchain Technology? A Step-by-Step Guide For Beginners.Retrieved 12 28, 2018, from Blockgeeks: https://blockgeeks.com/guides/what-is-blockchain-technology

Eirini C., S., Theodoros C., K., Nicolai, P., & Christos N., S. (2018). Proposal for an e-health Based Ecosystem Serving National Healthcare. *Journal of Biomedical and Health Informatics*, 13.

Fabian, E., Nangami, M., Tabu, J., Mwangi, A., Ayuku, D., & Were, E. (2017). A system approach to improving maternal and child health care delivery in Kenya: innovations at the community and primary care facilities (a protocol). *Reproductive Health*, 18.

Fagbamigbe, A. F., & Idemudia, E. S. (2017). Wealth and antenatal care utilization in Nigeria: Policy implications. *Health care for women international*. 38(1), 17–37. https://doi.org/10.1080/07399332.2016.1225743

Global. (2018). *Global Citizen*. Retrieved from Introduction to the challenges for maternal health.

Gordon, W., & Catalini, C. (2018). Blockchain Technology for Healthcare: Facilitating the Transition to Patient-Driven Interoperability. *Computational and Structural Biotechnology Journal*.

Grossmann, C., Goolsby, W. A., Olsen, L., & McGinnis, J. M. (2011). Healthcare System Complexities, Impediments, and Failures. In T. N. Press, *Engineering a Learning Healthcare System.* National Academies Press (US).

Gupta, O. (2019). Truffle - a framework for solidity smart contracts. Retrieved April 12, 2021, from https://qainfotech.com/truffle-a-framework-for-solidity-smart-contracts/

Health IT (2016). *health-information-exchange*. Retrieved 03 16, 2019, from healthit.gov: https://www.healthit.gov/topic/health-it-basics/health-information-exchange

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, 28(1).

Hevner, A., & Chatterjee, S. (2010). *Design research in information systems theory and practice.* Springer Science & Business Media.
https://bettercare.co.za/learn/maternal-care/text/01.html

Iansiti, M., & Lakhani, K. R. (2018). *The Truth About Blockchain*. Retrieved 12 28, 2018, from Harvard Business Review: https://hbr.org/2017/01/the-truth-about-blockchain

Iqbal, F. (2018). What is blockchain and how can it be used in healthcare? Retrieved from https://www.healthitoutcomes.com/doc/what-is-blockchain-and-how-can-it-be-used-in-healthcare-0001

Ivan, D. (2016). *Moving Toward a Blockchain-based Method for the Secure Storage of Patient Records*. 11.

Khatwani, S. (2018). *What is a Bitcoin Hash?* Retrieved 12 18, 2018, from CoinSutra - Bitcoin Community: https://coinsutra.com/bitcoin-hash/

Kihuba, E., Gathara, D., Mwinga, S., Mulaku, M., Kosgei, R., Mogoa, W., (2014). Assessing the ability of health information systems in hospitals to support evidence-informed decisions in Kenya. *Global Health Action*, 7.

Kirichu, C. N., Samuel, M., Nicodemus, M., & Jades, K. M. (2014). Adoption of Integrated Healthcare Information System in Nairobi County: Kenyatta National Hospital versus Mater Hospital. *International Journal of Computer Applications Technology and Research*, 685 - 692.

Kifle, D., Azale, T., Gelaw, Y., & Melsew, Y. (2017). Maternal health care service seeking behaviors and associated factors among women in rural Haramaya District, Eastern Ethiopia: a triangulated community-based cross-sectional study. Reproductive Health, 14(1). https://doi.org/10.1186/s12978-016-0270-5

Kiviat, T. (2015). Beyond Bitcoin: Issues in Regulating. *Duke Law Journal*, 65.

Kuo, T.T., Kim, H.-E., & Ohno-Machad, L. (2017). Blockchain distributed ledger technologies for biomedical and health care applications. *Journal of the American Medical Informatics Association*, *6*, 1211–1220.

Langlois, P. (2019, August 2). Rapid Prototyping: A Guide for UX Designers. Retrieved from https://www.framer.com/blog/posts/rapid-prototyping/

Lavin, M. A. (2015). Health Information Technology, Patient Safety, and Professional Nursing Care Documentation in Acute Care Settings. *Online Journal of Issues in Nursing*, 20.

Lawn, J., & Kerber, K. (2006). *Opportunities for Africa's newborns: practical data, policy and programmatic support for newborn care in Africa.* Cape Town.

Lund, S. (2018). Mobile phone innovations for maternal and neonatal health in low and middle income. *BJOG: An International Journal of Obstetrics & Gynaecology.*

Magee, T. (2018). Impressive Ways Blockchain Is Being Used in Enterprise. Retrieved 12 2018, 2018, from ComputerworldUK:

https://www.computerworlduk.com/galleries/security/how-could-blockchain-be-used-the-enterprise-3628558/

Malviya, H. (2017). *Its Blockchain*. Retrieved from 5 Basic Principals Of Blockchain Technology : What Makes Blockchain Different And Secure?: https://itsblockchain.com/5-basic-principals-of-blockchain-technology-make-blockchain-different-and-secure/

Marino, L. (2016). *Blockchain—The End of the Middleman*. Retrieved 12 28, 2018, from medium.com: https://medium.com/@LloydMarino/blockchain-the-end-of-the-middleman-37d97a67d7f

Marr, B. (2017). *A Complete Beginner's Guide To Blockchain*. Retrieved 12 28, 2018, from Forbes: https://www.forbes.com/sites/bernardmarr/2017/01/24/a-complete-beginners-guide-to-blockchain/#6cbc5eed6e60

Martin, L. (2018). *Blockchain or relational database? How to choose the right technology for your application*. Retrieved 12 18, 2018, from www.techbeacon.com: https://techbeacon.com/Blockchain-relational-database-which-right-for-your-application

Martin, L. (2018, 12 05). *Blockchain or relational database? How to choose the right technology for your application*. Retrieved 12 18, 2018, from www.techbeacon.com: https://techbeacon.com/Blockchain-relational-database-which-right-for-your-application

Martin, L. (2018, 12 05). *Blockchain or relational database? How to choose the right technology for your application*. Retrieved 12 18, 2018, from www.techbeacon.com: https://techbeacon.com/Blockchain-relational-database-which-right-for-your-application

mHealthK. (2018, 10 08). *mHealth Kenya Projects*. Retrieved from mHealth Kenya: https://mhealthkenya.org/projects

Ministry of Health. (2009). *Health Information System Policy 2009.* Kenya: Kenya Ministry of Health.

MOH. (2009). *Health Information System Policy 2009.* Kenya: Kenya Ministry of Health.

Moran, T. (2018). *The Ultimate Guide to Ethereum Developer Tools*. Retrieved 05 19, 2019, from www.hachernoon.com: https://hackernoon.com/the-ultimate-guide-to-ethereum-developer-tools-7feb53f9d953

Muinga, N., Magare, S., Monda, J., Kamau, O., Houston, S., Fraser, H., Powell, J., English, M., & Paton, C. (2018). Implementing an Open Source Electronic Health Record System in Kenyan Health Care Facilities: Case Study. *JMIR medical informatics*, 6(2), e22. https://doi.org/10.2196/medinform.8403

Nanda, V. (2019). The 7 types of evaluation you need to know. Retrieved from https://humansofdata.atlan.com/2017/04/7-types-of-evaluation/#GoalsBased_Evaluation

NASA. (2004). *NASA Software Safety Guidebook:* National Aeronautics and Space Administration.

Nazmul. (2018). *Effects of blockchain in today's supply chains*. Retrieved 12 28, 2018, from lteconomy: http://www.lteconomy.it/blog/2018/11/27/blockchains-affect-in-todays-supply-chains/

Njoroge, M., Zurovac, D., Ogara, E. A., Chuma, J., & Kirigia, D. (2017). Assessing the feasibility of eHealth and mHealth: A systematic review and analysis of initiatives implemented in Kenya. BMC Research Notes, 10(1). https://doi.org/10.1186/s13104-017-2416-0

Njuguna, J., Kamau, N., & Muruka, C. (2017). Impact of free delivery policy on utilization of maternal health services in county referral hospitals in Kenya. *BMC health services research*, 17(1), 429. https://doi.org/10.1186/s12913-017-2376-z

Patel, M. (2017). Blockchain Approach for Smart Health Wallet. *International Journal of Advanced Research in Computer and Communication Engineering*, 131-135.

Patton. (1990). Qualitative Evaluation and Research Methods. *Beverly Hills, CA: Sage.*, 169-186.

Planetree, I. (2017). *Patient-Preferred Practice Primer: Shared Medical Record.* Derby, CT: Planetree, Inc.

Pratap , M. (2018). *Blockchain in Healthcare: Opportunities, Challenges, and Applications*. Retrieved 12 18, 2018, from Hacker Noon: https://hackernoon.com/blockchain-in-healthcare-opportunities-challenges-and-applications-d6b286da6e1f

Rahel Abiy, K. G. (2018). A comparison of electronic records to paper records in Antiretroviral Therapy Clinic in Ethiopia: What is affecting the Quality of the Data? *Online Journal of Public Health Informatics*, 10(2): e212.

Razzouk, R., & Shute, V. (2012). What Is Design Thinking and Why Is It Important? Review of Educational Research, 82(3), 330–348. https://doi.org/10.3102/0034654312457429

Rothrei, S. (2019, April 1). 8 of the Best Blockchain Development Tools for Ethereum developers. CoinCentral. Retrieved November 11, 2021, from https://coincentral.com/blockchain-development-tools/.

Rynning, E. (2007). Public Trust and Privacy in Shared Electronic Health Records. *European Journal of Health Law*, 14 .

Sahu, M. (2019). *What is truffle suite? Features, how to install, how to run smart contracts*. Retrieved from https://www.upgrad.com/blog/what-is-truffle-suite/

Schönhals, A., Hepp, T., & Gipp, B. (2018). *Design thinking using the blockchain: enable traceability of intellectual property in problem-solving processes for open innovation. In Proceedings of the 1st Workshop on Cryptocurrencies and Blockchains for Distributed Systems* (105-110).

Siang, T. Y., & Dam, R. F. (2015). *5 stages in the design thinking process*. Retrieved from https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process.

Singaram, M., & Jain, P. (2018). *What is the Difference between Proof of Concept and Prototype* Retrieved 01 10, 2019, from entrepreneur.com: https://www.entrepreneur.com/article

Sinhasane, S. (2019). *What is health information system (HIS) & its importance*? Retrieved from https://mobisoftinfotech.com/resources/blog/importance-of-health-information-system/

Snell, E. (2018). *What are Potential Benefits, Challenges of HIE Use*. Retrieved 01 10, 2019, from her intelligence: https://ehrintelligence.com/news/what-are-potential-benefits-challenges-of-hie-use

Szewczyk, P. (2017). Potential Applications of the Blockchain. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 395-402.

Taliesin, B., Mwanyika, H., Ritz, D., Principal, Peloso, L., & Wilson, K. (2014). *Product Vision for the Better Immunization Data (BID) Initiative.* Retrieved 12 19, 2018, from www.path.org.: https://path.org/resources/product-vision-for-the-better-immunization-data-bid-initiative/

Tapscott, D., & Tapscott, A. (2016). *huffingtonpost*. Retrieved 12 2018, 2018, from Here's Why Blockchains Will Change the World:https://www.huffingtonpost.com/don-tapscott/heres-why-blockchains-wil_b_10146610.html

Thorsten Koeppl, J. K. (2017). Blockchain Technology – What's in Store for Canada's Economy and Financial Markets? *C.D. Howe Institute*, 28.

Tongco, M. D. C. (2007). Purposive Sampling as a Tool for Informant Selection. Ethnobotany Research and Applications, 5, 147. https://doi.org/10.17348/era.5.0.147-158

Trent McConaghy, R. M. (2016). *A Scalable Blockchain Database.* Berlin, Germany: ascribe GmbH.

Tsung-Ting Kuo, L. O. M. (2018). *Decentralized Privacy-Preserving Healthcare Predictive Modeling Framework on Private Blockchain Networks*. Computers and Society.

UNHCR (2010). Module 9 Part 1 - Antenatal Care. (n.d.). Retrieved October 29, 2020, from https://www.unhcr.org/en-ie/461e537b2.pdf

Uwizeyemungu, S., & Poba-Nzaou, P. (2017). Health Information Exchange and Related IT-security Practices in European Hospitals . *3rd International Conference on Information Systems Security and Privacy*, 538-545.

Verma, T. (2018). *Blockchain Technology Explained – Coinmonks – Medium*. Retrieved from Medium: https://medium.com/coinmonks/blockchain-technology-explained-7d68c4435aca

Virunurm, K., & Seeba, M. (2017). *Cryptographic algorithms lifecycle report 2017.* Tallinn, Estonia: Cybernetica AS.

WHO. (2010). 3. Health Information Systems - who. Retrieved October 29, 2020, from https://www.who.int/healthinfo/systems/WHO_MBHSS_2010_section3_web.pdf

WHO. (2016). *Integrated care models.* Marmorvej : World Health Organization.

WHO. (2018). *Maternal Health*. Retrieved 12 2018, 2018, from World Health Organization: https://www.who.int/maternal-health/en/

Williams, C., Mostashari, F., Mertz, K., Hogin, E., & Atwal, P. (2017). *What is HIE?* Retrieved 12 28, 2018, from HealthIT.gov: https://www.healthit.gov/topic/health-it-and-health-information-exchange-basics/what-hie

Zhang, P., White, J., Schmidt, D. C., & Lenz, G. (2017). Applying Software Patterns to Address Interoperability in Blockchain-based Healthcare Apps. CoRR, abs, 1706.03700.

Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017). An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. 2017 IEEE International Congress on Big Data (BigData Congress), 557-564.

Zwanenburg, J. V. (2018). *Decentralized Cloud Storage Platforms That Are Shaking Up The Industry*. Retrieved 12 28, 2018, from investinblockchain.com: https://www.investinblockchain.com/decentralized-cloud-storage-platforms/

Zyskind, G., Nathan, O., & Pentland, A. (2015). Decentralizing Privacy Using Blockchain to Protect Personal Data. *2015 IEEE Security and Privacy Workshops*, 180-184.

APPENDICES

Appendix I: Source Codes

Code Listing A - Hospital registration

```
pragma solidity 0.5.0;
// Importing OpenZeppelin's SafeMath Implementation
// import "https://github.com/OpenZeppelin/openzeppelin-solidity/contracts/math/SafeMath.sol";
import "./Hospital.sol";
import "./MaternityHandbook.sol";
import "./Patient.sol";
contract HospitalRegistry {
   address owner;
  constructor() public {
      owner = msg.sender;
   }
   //List of all hospitals
   Hospital[] private hospitals;
   Patient[] private patients;
   MaternityHandbook[] private maternity_handbooks;
   mapping(string => MaternityHandbook[]) private patient_records;

   //event hospital added
   event HospitalStarted(
      address contractAddress,
      address ownder,
      string name,
      string aboutMe
   );
   //event patient added to registry
   event PatientRegistered(
      address patientAddress,
      string username,
```

```
    string otherData
);
//event health record added to registry
event HealthRecordCreated(
    address mhandbookAddress,
    address patientAddress,
    string otherData
);
//Create a hospital
function createHospital(
    string calldata name,
    string calldata username,
    string calldata otherData
    ) external {

    Hospital newHospital = new Hospital(
      msg.sender,
      name,
      username,
      otherData
    );

    hospitals.push(newHospital);

    emit HospitalStarted(
        address(newHospital),
        msg.sender,
        name,
        otherData
    );
}

function createPatient(
    address payable hospitalAddress,
```

```
        address payable patientAddress,
        string calldata fullName,
        string calldata username,
        string calldata otherData
        ) external {

        Patient newPatient = new Patient(hospitalAddress, patientAddress, fullName,
username, otherData);
        patients.push(newPatient);

         emit PatientRegistered(
            patientAddress,
            username,
            otherData
         );
    }

    function create-health Record(
        address payable patientAddress,
        address payable hospitalAddress,
        string calldata patientUsername,
        string calldata otherData
        ) external {

        MaternityHandbook newRecord = new
MaternityHandbook(patientAddress,hospitalAddress, patientUsername, otherData);
        maternity_handbooks.push(newRecord);

        patient_records[patientUsername].push(newRecord);

         emit HealthRecordCreated(
            address(newRecord),
            patientAddress,
            otherData
```

```
        );
    }
    function returnAllHospitals() external view returns(Hospital[] memory){
        return hospitals;
    }
    function returnAllPatients() external view returns(Patient[] memory){
        return patients;
    }
    function returnAllHealthRecords() external view returns(MaternityHandbook[]
memory){
        return maternity_handbooks;
    }
    function returnAllPatientRecords(string memory username) public view returns (
      MaternityHandbook[] memory handbooks
    ){
      return patient_records[username];
    }
}pragma solidity 0.5.0;
// Importing OpenZeppelin's SafeMath Implementation
// import "https://github.com/OpenZeppelin/openzeppelin-
solidity/contracts/math/SafeMath.sol";
import "./Hospital.sol";
import "./MaternityHandbook.sol";
import "./Patient.sol";

contract HospitalRegistry {
    address owner;

  constructor() public {
        owner = msg.sender;
    }
    //List of all hospitals
    Hospital[] private hospitals;
    Patient[] private patients;
```

```
MaternityHandbook[] private maternity_handbooks;
mapping(string => MaternityHandbook[]) private patient_records;

//event hospital added
event HospitalStarted(
    address contractAddress,
    address ownder,
    string name,
    string aboutMe
);
//event patient added to registry
event PatientRegistered(
    address patientAddress,
    string username,
    string otherData
);
//event health record added to registry
event HealthRecordCreated(
    address mhandbookAddress,
    address patientAddress,
    string otherData
);
//Create a hospital
function createHospital(
    string calldata name,
    string calldata username,
    string calldata otherData
    ) external {
    Hospital newHospital = new Hospital(
      msg.sender,
      name,
      username,
      otherData
    );
```

```
        hospitals.push(newHospital);
        emit HospitalStarted(
            address(newHospital),
            msg.sender,
            name,
            otherData
        );
    }

    function createPatient(
        address payable hospitalAddress,
        address payable patientAddress,
        string calldata fullName,
        string calldata username,
        string calldata otherData
        ) external {

        Patient newPatient = new Patient(hospitalAddress, patientAddress, fullName,
username, otherData);
        patients.push(newPatient);

         emit PatientRegistered(
             patientAddress,
             username,
             otherData
         );
    }
    function create-health Record(
        address payable patientAddress,
        address payable hospitalAddress,
        string calldata patientUsername,
        string calldata otherData
        ) external {
```

```
        MaternityHandbook newRecord = new
MaternityHandbook(patientAddress,hospitalAddress, patientUsername, otherData);
        maternity_handbooks.push(newRecord);
        patient_records[patientUsername].push(newRecord);
         emit HealthRecordCreated(
            address(newRecord),
            patientAddress,
            otherData
         );
    }

    function returnAllHospitals() external view returns(Hospital[] memory){
        return hospitals;
    }

    function returnAllPatients() external view returns(Patient[] memory){
        return patients;
    }

    function returnAllHealthRecords() external view returns(MaternityHandbook[]
memory){
        return maternity_handbooks;
    }
    function returnAllPatientRecords(string memory username) public view returns (
      MaternityHandbook[] memory handbooks
    ){
      return patient_records[username];
    }
}
```

Code Listing B - patient import from another facility

```
<script>
import {Card} from “@/components/index”;
import web3 from “@/contracts/web3”;
import healthRegistry from “@/contracts/abi/HospitalRegistry”;
```

```
import patient from “@/contracts/abi/Patient”;
import sms from “@/Sms”;

export default {
components: {
Card
},
mounted() {
this.$store.watch(
(state, getters) => getters.hospitalAddress,
(newV, old) => {
if (newV === null) {
this.$router.push({path: “/registry”});
}
});
},
data() {
return {
patient: {},
search: {
username: ““
},
requesting_access: false,
verify_phone: false,
code: null,
confirm_code: null,
access: {
code: 0,
verify_code: null,
}
};
},
computed: {
account() {
```

```
console.log(this.$store.state.account);
return this.$store.state.account;
},
isLoggedIn() {
return this.$store.state.isLoggedIn;
},
hospital() {
return this.$store.state.hospitalAddress;
}
},
methods: {
verifyPhone() {
this.verify_phone = !this.verify_phone;
if (this.verify_phone) {
this.code = Math.floor(Math.random(1001, 9999) * 10000);
if (!window.debug)
sms
.send({
to: this.patient.phone,
message: “Maternal Health Account Verification code: “ + this.code
})
.then(response => {
console.log(response);
})
.catch(error => {
console.log(error);
});
else this.patient.verify_phone_code = this.code;
}
},
searchPatient() {
this.requesting_access = !this.requesting_access;
if(this.requesting_access){
healthRegistry.methods
```

```
.returnAllPatients()
.call()
.then(patients => {
patients.forEach(address => {
const pInst = patient(address);
pInst.methods
.getDetails()
.call()
.then(pData => {
const pInfo = pData;
pInfo.contract = pInst;
var json = String.fromCharCode(...pInfo._otherData.split(" "));
pInfo.form = JSON.parse(json);
pInfo.form.account = pInfo.contract._address;
if(this.search.username === pInfo._username){
this.access.patient = pInfo;
this.access.code = Math.floor(Math.random(1001, 9999) * 10000);
sms
.send({
to: pInfo.form.phone,
message: "Maternal Health Account Access Verification code: " + this.access.code
})
.then(response => {
console.log(response);
this.$notify('Patient found and access verification code sent.')
})
.catch(error => {
console.log(error);
this.$notify('Failed to send access verification code. p.s try again.')
});
}
});
});
});
```

```
}
},
proceedSearch() {
//this.$router.push({path: '/patients'})
if(this.access.verify_code === this.access.code.toString()){
this.$notify('Access granted. Viewing patient information')
this.$router.push({path: `patient-records/${this.access.patient.contract._address}`});
}else{
this.$notify('Access code does not match. Please try again.');
}

},
savePatient() {
var vm = this;
if (this.code.toString() === this.patient.verify_phone_code) {
console.log(JSON.stringify(this.patient));
var json = JSON.stringify(this.patient);
var other = "";
for (var x = 0; x < json.length; x++) {
if (x <= json.length - 2) other += String(json.charCodeAt(x)) + " ";
else other += json.charCodeAt(x);
}
```

Code Listing C - Patient registration

```
<script>
import LZString from 'lz-string';
import {PaperTable} from "@/components";
import healthRegistry from "@/contracts/abi/HospitalRegistry";
import patient from "@/contracts/abi/Patient";
import handbook from "@/contracts/abi/MaternityHandbook";
const previous_pregnancy_cols = [
"Pregnancy Order",
"Year",
"Number of Times ANC attended",
```

```
“Place of Delivery”,
“Maturity”,
“Duration of Labor”,
“Type of Delivery”,
“Birth weight”,
“Sex”,
“Outcome”,
“Puerperium”
];
const clinical_notes_cols = [“Date”, “Clinical Notes”];
const pren_preg_cols = [
“No of visits”,
“Date”,
“Urine”,
“Weight”,
“Bp”,
“Hb”,
“Pallor”,
“Maturity”,
“Fundal Height”,
“Presentation”,
“Lie”,
“Foetal Heart”,
“Foetal Movt”,
“Next Visit”
];
export default {
components: {
PaperTable
},
data() {
return {
patient: {
```

```
form: {}
},

pren_preg_item: {},
previous_pregnancy_item: {},
clinical_note: {},


handbook: {
prev_preg_fields: [...previous_pregnancy_cols],
previous_pregnancy: {
columns: [...previous_pregnancy_cols, “Actions”],
data: []
},

clinical_notes_fields: [...clinical_notes_cols],
clinical_notes: {
columns: [...clinical_notes_cols, “Actions”],
data: []
},

pren_preg_fields: [...pren_preg_cols],
pren_preg_tbl: {
columns: [...pren_preg_cols, “Actions”],
data: []
},

preventive_services: {
columns: [“Service”, “Date”, “Next Visit”],
data: [
{
service: “** Tetanus toxoid 1”,
date: ““,
next_visit: ““
```

},
{
service: “Tetanus toxoid 2”,
date: ““,
next_visit: ““
},
{
service: “Tetanus toxoid 3”,
date: ““,
next_visit: ““
},
{
service: “Tetanus toxoid 4”,
date: ““,
next_visit: ““
},
{
service: “Tetanus toxoid 5”,
date: ““,
next_visit: ““
},
{
service: “* Malaria Prophylaxis (IPT1) at 16 weeks”,
date: ““,
next_visit: ““
},
{
service: “Malaria Prophylaxis (IPT2) at 4 weeks”,
date: ““,
next_visit: ““
},
{
service: “Malaria Prophylaxis (IPT3) at 4 weeks”,
date: ““,

```
next_visit: ““
},
{
service: “Malaria Prophylaxis (IPT4) at 4 weeks”,
date: ““,
next_visit: ““
},
{
service: “Malaria Prophylaxis (IPT5) at 4 weeks”,
date: ““,
next_visit: ““
},
{
service: “Malaria Prophylaxis (IPT6) at 4 weeks”,
date: ““,
next_visit: ““
},
{
service: “Malaria Prophylaxis (IPT7) at 4 weeks”,
date: ““,
next_visit: ““
}
]
}
},

handbooks: []
};
},
computed: {
account() {
return this.$store.state.account;
},
isLoggedIn() {
```

```
return this.$store.state.isLoggedIn;
},
hospital() {
return this.$store.state.hospitalAddress;
}
},
created() {
this.getAllPatientRecords();
},
methods: {
addPrevPreg() {
this.handbook.previous_pregnancy.data.push(this.previous_pregnancy_item);
this.previous_pregnancy_item = {};
},
addClinicalNote() {
this.handbook.clinical_notes.data.push(this.clinical_note);
this.clinical_note = {};
},
addPrenPreg() {
this.handbook.pren_preg_tbl.data.push(this.pren_preg_item);
this.pren_preg_item = {};
},
getAllPatientRecords() {
const pInst = patient(this.$route.params.account);
pInst.methods
.getDetails()
.call()
.then(pData => {
const pInfo = pData;
pInfo.contract = pInst;
var json = String.fromCharCode(...pInfo._otherData.split(“ “));
pInfo.form = JSON.parse(json);
pInfo.form.account = pInfo.contract._address;
this.patient = pInfo;
```

```
healthRegistry.methods
.returnAllPatientRecords(this.patient.form.username)
.call()
.then(handbooks => {
handbooks.forEach(address => {
const hInst = handbook(address);
hInst.methods
.getDetails()
.call()
.then(hData => {
const hInfo = hData;
hInfo.contract = hInst;
console.log("mh info");
let json = String.fromCharCode(
...hInfo._otherData.split(" ")
);
json = LZString.decompress(json);
console.log(json);
hInfo.handbook = JSON.parse(json);
this.handbook = hInfo.handbook;
this.handbooks.push(hInfo);
});
});
});
});
},
saveHandBook() {
this.progress = true;
var vm = this;
var json = JSON.stringify(this.handbook);
var other = "";

console.log("Size of sample is: " + json.length);
```

```
var compressed = LZString.compress(json);
console.log(compressed);
console.log("Size of compressed sample is: " + compressed.length);
var string = LZString.decompress(compressed);
console.log("Sample is: " + string);

other = compressed;
console.log(other);
let bytestr ="";
for (var x = 0; x < other.length; x++) {
if (x <= other.length - 2) bytestr += String(other.charCodeAt(x)) + " ";
else bytestr += other.charCodeAt(x);
}

console.log(bytestr.length);
console.log(bytestr);

healthRegistry.methods
.create-health Record(this.patient.contract._address, this.hospital,
this.patient.form.username, bytestr)
.send({
from: this.account
})
.on("confirmation", (confirmationNumber, receipt) => {
vm.progress = false;
console.log(confirmationNumber, receipt);
// this.$router.push({path: "/patients"});
})
.on("receipt", (confirmationNumber, receipt) => {
vm.progress = false;
console.log(confirmationNumber, receipt);
this.$router.push({path: "/patients"});
})
.on("error", error => {
```

```
vm.progress = false;
console.log(error);
});
}
}
};
</script>
<style>
.card-body {
padding: 10px 0 8px;
}
</style>
```

Code Listing D - Patient health care records

```
script>
import LZString from 'lz-string';
import {PaperTable} from “@/components”;
import healthRegistry from “@/contracts/abi/HospitalRegistry”;
import patient from “@/contracts/abi/Patient”;
import handbook from “@/contracts/abi/MaternityHandbook”;

const previous_pregnancy_cols = [
“Pregnancy Order”,
“Year”,
“Number of Times ANC attended”,
“Place of Delivery”,
“Maturity”,
“Duration of Labor”,
“Type of Delivery”,
“Birth weight”,
“Sex”,
“Outcome”,
“Puerperium”
];
const clinical_notes_cols = [“Date”, “Clinical Notes”];
```

```
const pren_preg_cols = [
“No of visits”,
“Date”,
“Urine”,
“Weight”,
“Bp”,
“Hb”,
“Pallor”,
“Maturity”,
“Fundal Height”,
“Presentation”,
“Lie”,
“Foetal Heart”,
“Foetal Movt”,
“Next Visit”
];

export default {
components: {
PaperTable
},
data() {
return {
patient: {
form: {}
},

pren_preg_item: {},
previous_pregnancy_item: {},
clinical_note: {},

handbook: {
prev_preg_fields: [...previous_pregnancy_cols],
previous_pregnancy: {
```

```
columns: [...previous_pregnancy_cols, “Actions”],
data: []
},

clinical_notes_fields: [...clinical_notes_cols],
clinical_notes: {
columns: [...clinical_notes_cols, “Actions”],
data: []
},

pren_preg_fields: [...pren_preg_cols],
pren_preg_tbl: {
columns: [...pren_preg_cols, “Actions”],
data: []
},

preventive_services: {
columns: [“Service”, “Date”, “Next Visit”],
data: [
{
service: “** Tetanus toxoid 1”,
date: ““,
next_visit: ““
},
{
service: “Tetanus toxoid 2”,
date: ““,
next_visit: ““
},
{
service: “Tetanus toxoid 3”,
date: ““,
next_visit: ““
},
```

{
service: “Tetanus toxoid 4”,
date: ““,
next_visit: ““
},
{
service: “Tetanus toxoid 5”,
date: ““,
next_visit: ““
},
{
service: “* Malaria Prophylaxis (IPT1) at 16 weeks”,
date: ““,
next_visit: ““
},

Appendix II: Research Authorization Letter

KABARAK UNIVERSITY

Private Bag - 20157
KABARAK, KENYA
http://kabarak.ac.ke/institute-postgraduate-studies/

Tel: 0773 265 999
E-mail: directorpostgraduate@kabarak.ac.ke

BOARD OF POSTGRADUATE STUDIES

18th July, 2019

The Director General
National Commission for Science, Technology & Innovation (NACOSTI)
P.O. Box 30623 – 00100
NAIROBI

Dear Sir/Madam,

RE: ANTHONY GUYA MUSABI- REG. NO. GMI/NE/0218/01/18

The above named is a Master's of Science student at Kabarak University in the School of Science, Engineering and Technology. He is carrying out research entitled ***"Enabling Secure Maternal Health Information Exchange using Blockchain"***. He has defended his proposal and has been authorized to proceed with field research.

The information obtained in the course of this research will be used for academic purposes only and will be treated with utmost confidentiality.

Please provide him with a research permit to enable him to undertake his research.

Thank you.

Yours faithfully,

Dr. Betty Jeruto Tikoko
DIRECTOR, POSTGRADUATE STUDIES

KABARAK UNIVERSITY
DIRECTOR
POST GRADUATE STUDIES
18 JUL 2019
PRIVATE BAG -20157, KABARAK

Kabarak University Moral Code

As members of Kabarak University family, we purpose at all times and in all places, to set apart in one's heart, Jesus as Lord. (1 Peter 3:15)

Appendix III: NACOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **700702**

Date of Issue: **09/September/2019**

RESEARCH LICENSE

This is to Certify that Mr.. Antony Musabi of Kabarak University, has been licensed to conduct research in Nakuru on the topic: Enabling Secure Maternal Health Information Exchange Using Blockchain for the period ending : 09/September/2020.

License No: **NACOSTI/P/19/715**

700702

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

Appendix IV: Nakuru County Referral Hospital Payment Receipt

Q-Afya Receipts http://192.168.0.20/backup/report.php?id=62&print=0&rcptno=15...

RIFT VALLEY PGH

P.O BOX 05171 NAKURU

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OFFICIAL RECEIPT

704706

DATE:07/10/2019 TIME:12:58 PM
RECEIPT NO: 704706 DEPT: ATTACHMENT FEE

PATIENT NAME: ANTONY GUYA MUSABI
O/P NO:
SYSTEM NO: PGH-232834

ITEM NAME	QTY/PRICE	TOTAL
RESEARCH OTHER INSTITUTIONS	1 X 3000	3,000.00
TOTAL	1	3,000.00

TOTAL AMOUNT BILLED	3,000.00
AMOUNT PAID IN CASH	3,000.00

WE WISH YOU QUICK RECOVERY.

C.I.C 07/10/2019

1 of 2 9/21/2020, 3:25 PM

Appendix V: Expert Interview Questions Guide

Q1. What is the current method used in sharing of information in the antenatal care process?

(The current method used in dissemination of information in the antenatal care process)

- Kind of information captured
- Information is manual or automated
- Sequence of reports and technical capabilities of the mother

Q2. What are the current approaches of Maternal Health Information Exchange within the antenatal health care process?

(The current approaches of Maternal Health Information Exchange within the antenatal health care process.)

- Current approaches
- Current process
- Information captured and collected from the patient
- Role of the District Health Information System2 (DHIS2) within the ANC process.

Q3. What are the challenges facing Maternal Health Information exchange within the antenatal health care process?

(The identified Challenges and Weaknesses of the Existing Maternal Healthcare Information Exchange Models)

- Challenges faced by health service providers during.
- Challenges faced by the hospital administrators.
- Would providing an automated solution for one solves the challenge for another

Appendix VI: Expert Survey Question

Using the scale kindly indicate whether the prototype has demonstrated the following aspect

Q1. The ability to capture and store information accurately **(Accuracy of Data collected)**

Q2. The ability to provide continuity of care when a mother visits different facility (**Continuity of Care)**

Q3. Has shown the validity and transparency of data collected **(Decentralization)**

Q4. Has shown that an author cannot deny the validity of data entered and cannot be changed or be modified. **(Non-Repudiation and Immutability)**

Q5. The aspect of ensuring only authorized users and owners can access the data **(Authentication)**

Q6. The provision of a redundant back-up and data retrieval in case of data loss. **(Redundancy and Data Stewardship)**

Q7. The ability of providing a summary of data collected. (**Data Reporting)**

Appendix VII: Nakuru County Referral Hospital

REPUBLIC OF KENYA
DEPARTMENT OF HEALTH SERVICES
NAKURU COUNTY

Email:Rvpghnakuru@Yahoo.Com
When Replying Please Quote
Mobile; +254721750460

Nakuru Level 5 Hospital
Nakuru County
P. O. BOX 71-20100
NAKURU

31st August, 2020

To
The Institute of Post Graduate Studies,
Kabarak University,
PO BOX Private Bag, 20157,
Kabarak

Dear Sir/Madam,

RE: MUSABI ANTONY GUYA.
The above named student was conducting research in this Institution on "Enabling secure Mental Health Information Exchange using Block Chain", which he successfully undertook in 2019.

Any assistance accorded to him will be highly appreciated.

HUMAN RESOURCE I/C
For
MEDICAL SUPERITENDENT
NAKURU LEVEL 5 HOSPITA

JOSEPHAT W. MWANGI
For: MEDICAL SUPERITENDENT
NAKURU LEVEL 5 HOSPITAL.

Appendix VII: Published Articles

1. **Conference Proceedings**

Proceedings of the Kabarak University International Research Conference on Computing and Information Systems
5th - 9th October 2020 Nakuru, Kenya.

Challenges of Health Information Exchange in Maternal Healthcare in Kenya

A Case Study of Nakuru County Level 5 Hospital.

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Abstract: In Kenya, Medical facilities have made efforts to adopt Electronic Health Records systems at various levels and for different use cases. However, there lacks a robust and secure system for sharing sensitive and confidential health records. This curtails the potential benefits that can be gained by shared electronic health records especially the antenatal care process. Besides, there lacks a portable mechanism of sharing patient medical history especially when the patient seeks care from one provider to another. This situation is even dire and most detrimental to the most vulnerable of citizens, in expectant mothers, children and marginalized groups. This study seeks to determine the challenges of Health Information Exchange in Maternal healthcare, Antenatal Care Process. The findings were drawn from a qualitative research study conducted at the Nakuru County Level Five Hospital utilizing a case study methodological approach

Key Words: *Electronic Health Records systems, Health Information Exchange.*

1. Introduction

Like other developing countries the achievement of universal health coverage in Kenya has been prioritized by the current government for the period 2017 – 2022. There is a key focus on the following areas as part of these efforts: reproductive health, maternal health neonatal, child and adolescent health (MOH, 2009). To this end, the Kenyan government has made a number of key efforts such as the introduction of free maternity with an aim of increasing access to skilled delivery service, beyond zero campaign, aiming to improve maternal and child health outcomes in the country, among others.

However, these efforts are yet to bear much fruit given that the offering of these services is still largely facility-specific and relies on manual records where data captured are retained by the patients and at the same time transcribed on a clinical register for the health facility so that health facilities can have a record of the encounters (Sue Bowman, 2013). Much of this intervention is evident in antenatal care process; during this care process, Professional health workers normally use the Antenatal Health Cards as a medical tool for recording patient data (Adeniyi Francis Fagbamigbe, 2017). The data in these registers form the basis for the compilation of required routine reports (Chawani, 2014).

This, as a result, prevents continuity of care when mothers move from one location to another, Incomplete and inconsistency of data collection, inaccurate and unreliable reports, records redundancy, data inaccessibility, missing data in the records due to regular

Publication

International Journal of Information Technology (IJIT) – Volume 7 Issue 6, Nov - Dec 2021

RESEARCH ARTICLE OPEN ACCESS

Implementation of a Blockchain based model for Health Information Exchange in Maternal Healthcare

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[1],[2],[3] Department of Computer Science - Kabarak University

ABSTRACT

Medical facilities in Kenya have adopted Electronic Health Records systems but lack a robust and secure system for sharing sensitive and confidential health records. These efforts do not provide comprehensive data integrity and non-repudiation of patient medical history as the patient seeks care from one provider to another. This situation is even dire and most detrimental to the most vulnerable of citizens, in expectant mothers, children and marginalized groups. These shared electronic health records which includes provision of historical health information, is critical to facilitate making of informed medical decisions. Therefore, a blockchain based solution would reliably address these concerns and result in access to better quality maternal healthcare services in Kenya. The study focused on developing a Blockchain based model for secure Maternal Health Information Exchange. The solution targeted inter health facilities information interchange while ensuring data protection and access to information. The study utilized a mixed method approach entailing design thinking methodology.

Keywords: - Electronic Health Records, Maternal Health, Blockchain, Information Exchange.

I. INTRODUCTION

The Kenyan government has made a number of key efforts such as the introduction of free maternity with an aim of increasing access to skilled delivery service, beyond zero campaign, aiming to improve maternal and child health outcomes in the country, among others (Njuguna, Kamau, & Muruka, 2017) [1]. Much of this intervention is evident in antenatal care process; during this care process a Professional health workers normally use the Antenatal Health Cards as a medical tool for recording a patient data (Lincetto, Mothebesoane-Anoh, Gomez, & Munjanja, 2016) [2]. The data in these registers form the basis for compilation of required routine reports (Chawani, 2014) [3].
Incomplete and inconsistency of data collection, inaccurate and unreliable reports, records redundancy, data inaccessibility, missing data in the records due to regular oversight, and data being difficult to read as records grow so large over time (Lincetto, Mothebesoane-Anoh, Gomez, & Munjanja, 2016) [4]. In addition the process is tedious and difficult to extract data from it for clinical research and reporting in health centers. (Kihuba E., 2014) (Chao, 2016) [5]. The challenge of ensuring continuity of care is one that has been addressed in many other settings such as National Commission on Correctional Health Care (NCCHC), Policy health projects Kenya, through the use of ICT's. The Kenya Government has also recognized that eHealth and mHealth solutions as a key strategic direction towards achieving this goal and is ably captured in the Kenya National eHealth policy 2016 – 2030 for the maternal and other health programs. To address the challenges facing the effective application of eHealth Kenya Government through the ministry of health has outlined a number of key measures in the eHealth policy 2016 – 2030. Key among these measures is the development of platforms for cross-border and inter facility sharing of health information about the medical incidences and history of patients without compromising privacy (MOH, 2016) [6].
Health Information Exchange (HIE) is a dissemination system for medical or healthcare data between different parties. It involves mobilization of health care information electronically across organizations within regions, community or hospital system (Williams, Mostashari, Mertz, Hogin, & Atwal, 2017) [7]. Consequently it guarantees accuracy by ensuring, every party involved in a patient's care whether in a primary care setting, a specialists' health institutions has access to the same information (Uwizeyemungu & Poba-Nzaou, 2017) [8].
Healthcare providers interact in health information exchange which in-turn helps facilitate coordinated patient care, reduce duplicative treatments and avoid costly mistakes (athenahealth, 2018) [9]. HIE encourages efficient care by enabling automatic appointment reminders or follow-up instructions to be sent directly to patients, and prescriptions directly to pharmacies which reduces the amount of time patients spend filling out paperwork and briefing their