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A Blockchain-based prototype for car registration.

Njoroge, Nikita Thuo
Faculty of Information Technology
Strathmore University

A Blockchain-Based Prototype for Car Registration

Submitted By:

Nikita Thuo Njoroge

091772

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Declaration and Approval

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

Name: Nikita Thuo Njoroge

Student No: 091772

Signature: ……………………….

Date: …………………………….

Approval

The dissertation of Nikita Thuo Njoroge was reviewed and approved by the following:

Dr. Joseph Sevilla,
Director of @iLabAfrica,
Strathmore University.

Dr. Joseph Orero,
Dean, Faculty of Information Technology,
Strathmore University.

Dr. Bernard Shibwabo,
Director of Graduate Studies,
Strathmore University.

Abstract

Vehicle registration is an important exercise as it assists various departments including motor vehicle authorities, the police and tax authorities to make use of vehicle registration details for purposes of determining legitimate vehicle owners. Various methods including mobile and web technologies have been adopted in the registration of motor vehicles.

However, inconsistencies have always emerged in the vehicle ownership details. Current vehicle registration systems have not been able to mitigate against the threat of tampering with vehicle owners' details or at least keep track of the fraudulent transactions in the system. This has informed the need to review the current motor vehicle registration systems as well as the challenges faced in the registration of vehicle ownership details.

Based on the weaknesses of the current systems this research focused on developing a prototype based on the blockchain technology that ensured there was proper trail of all the transactions that were performed in the system including vehicle registration, transfer of vehicle ownership as well as confirmation of ownership transfer. The proposed development of the product adopted agile methodology in its software development lifecycle.

With known participants needed in a vehicle registration system, the study established that a permissioned blockchain was best suited to create the blockchain network. Hyperledger Fabric framework was therefore used to create the blockchain network, the reason being it is an enterprise-grade, permissioned, distributed ledger technology platform for use in enterprise contexts. This means Hyperledger Fabric offers features that are required or essential in enterprise applications. Android platform was used for development of the mobile application and AngularJS used for the web portal.

The tests done on the prototype were functional testing with 70% of the test cases indicating satisfied. Usability testing with 85% of the responses indicating that the system was user friendly. Finally, compatibility testing with the mobile application running efficiently on most of the Android versions and the web application was compatible with the major web browsers, Internet Explorer version 4 and above, Mozilla Firefox version 4 and above and Google chrome on all versions.

Keywords: Blockchain, Hyperledger Fabric, Ledger, Smart Contract, Chaincode, Consensus.

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List of Abbreviations/Acronyms

KRA – Kenya Revenue Authority

MVA – Motor Vehicle Administration

MVR – Motor Vehicle Register

MVRS – Motor Vehicle Registration System

NTSA – National Transport and Safety Authority

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Chapter One: Introduction

1.1 Background Information

Day by day the human population is increasing and use of vehicles is also increasing due to increased human needs. As a result of it, the control of vehicles is becoming a big complex problem for the transport industry (Tejas, Omkar , Rutuja, Prajakta, & Bhakti, 2017). The best way to ensure the control of vehicles is by registering the vehicles for purposes of capturing vehicle details, owner identification information as well as the vehicle population (American Association of Motor Vehicle Administrators, 2013).

Vehicle registration is therefore the process of adding a vehicle to a Motor Vehicle Register (MVR) and issuing it with registration number plates while a vehicle registration system is a repository of the vehicle particulars such as type of vehicle, make of vehicle and vehicle owner's details (James, Ansa, & Udoeka, 2016).

Current Motor Vehicle Registration Systems (MVRS) exist as mobile-web applications (James, Ansa, & Udoeka, 2016). Both the mobile and web applications gather vehicle information and end up relaying the information to a backend server which in turn perform the authentication of users' details (Tejas, Omkar , Rutuja, Prajakta, & Bhakti, 2017). It is worth noting that these systems are a functional domain of various stakeholders like the taxation departments, security and legal departments, environmental authorities as well as vehicle inspection units (Trucking Policy, 2017)

Nearly every jurisdiction has a Motor Vehicle Administration (MVA) that is responsible for vehicle registration and other entities authorised by MVAs to register vehicles (American Association of Motor Vehicle Administrators, 2013). The body responsible for motor vehicle registration in Kenya is the National Transport and Safety Authority (NTSA). Some of the services offered by NTSA on their portal include car registration, transfer of car ownership, change of particulars, duplicate logbook application, reflective number plate application, vehicle inspection and online car search (NTSA, 2017).

One of the problems associated with the current vehicle registration systems is the lack of mechanism to keep track of the system transactions when an unauthorised change of the car ownership details occur. A case in point is when a vehicle owner upon transferring the car ownership to a new buyer, can still tamper with the records and change the car ownership to a third party who happens not to own the car for malicious intentions (Musambi, 2018).

To overcome this challenge, the need to adopt blockchain technology is proposed. Blockchain is a technology that creates a storage of timestamped data ensuring that neither party can tamper with the contents of the data or timestamps without detection (Pierro, 2017). Consider the case of vehicle registration. The vehicle owner can be considered as the party to whom the vehicle was last sold to but that ownership is verifiable from the full paper trail of all transactions related to the car, a paper trail which is in the custody of the vehicle companies. The technology in itself does not prevent fraudulent transactions, but when they happen, they are detected and true ownership of the vehicle is detected.

1.2 Problem Statement

Determining vehicle ownership has been a key challenge due to significant variance in the vehicle registration details issued by Motor Vehicle Administrations as a result of fraudulent transactions. Current systems lack measures that help keep track of all transactions taking place with regards to vehicle registration and vehicle ownership transfer. This results to inconsistencies in vehicle registration details making it difficult for various stakeholders to be able to determine legitimate vehicle owners especially when registering vehicles and transferring vehicle ownership to new owners.

1.3 Research Objectives

i. To establish the challenges faced when keeping track of vehicle registration and vehicle ownership transfer transactions.
ii. To review the existing vehicle registration models and the challenges they face.
iii. To design, develop and test a blockchain-based solution for vehicle registration.
iv. To validate the proposed blockchain-based solution.

1.4 Research Questions

i. What are the challenges faced when keeping track of vehicle registration and vehicle ownership transfer transactions?
ii. What are the existing vehicle registration models being used and the challenges they face?
iii. How can a blockchain-based solution be designed, developed and tested for vehicle registration?
iv. How can the blockchain-based solution assist in tracking ownership of vehicles after registration?

1.5 Justification of the Study

Motor Vehicle Registration Systems (MVRS) are important functional organs of various authorities like the taxation departments, security and legal departments, environmental authorities and vehicle inspection units (Trucking Policy, 2017). It is mandatory that these systems are efficient and highly reliable in detecting fictitious vehicle registrations, malicious registrations as well as legal vehicle owners (James, Ansa, & Udoeka, 2016). Fraudulent transactions ought to be flagged for clean-up so as to arrive at a reliable and accurate database of vehicles and ownership through registration of existing vehicle population (Trucking Policy, 2017). The vehicle information maintained in the database will be used by decision makers for monitoring and enforcement of related laws by the National Transport and Safety Authority (NTSA), Kenya Revenue Authority (KRA) as well the Kenya Police.

1.6 Scope of the Study

This study will be carried out in the County of Nairobi taking into account individual owned vehicles. Nairobi is preferred due to its proximity to the researcher. Attention will be focused on car registration model(s) currently being used in Kenya. The study will seek to investigate and discuss problems of the existing model, possible solutions to address the problems, analysis, development, implementation and testing details of the proposed solution. The system will be limited to vehicle registrations, transfer of vehicle ownership and confirmation of ownership transfer with the target audience being those who possess smart-phones. The deliverable of this research will be both a mobile and web application that uses blockchain technology.

Chapter Two: Literature Review

2.1 Overview

This chapter covers the literature review. It analyses the problems associated with vehicle registration by reviewing the challenges of the existing vehicle registration models. Focus is on how to keep track of all transactions that relate to registration of vehicles. This research therefore discusses the technologies used in the development of a vehicle registration system and how a blockchain-based prototype for registering vehicles will be developed and tested to ascertain its viability.

2.2 Vehicle Inventory and Ownership

More than one billion vehicles are driven globally today with United States of America leading in the number of vehicles with the number expected to double globally in the next two decades (Sperling & Gordon, 2009). Africa had just over 42.5 million registered vehicles in 2014 according to Deloitte (2016) while Kenya had more than two million vehicles registered as of 2012 with the number projected to rise above 5 million by the year 2030 (Kenduiwo, 2015).

Despite the challenges experienced in the registration of vehicles, the number of vehicles is expected to increase by 3 percent globally (Sperling & Gordon, 2009). The European Union alone had 13.7 million car registrations as of the year 2015 which represented a million more vehicles registered than the previous year (International Council of Clean Transportation, 2017). A report done by Deloitte (2016) showed that Africa had approximately 1.55 million vehicle registrations in 2015 with vehicle sales projected to reach up to 10 million units per year in the next 15 years. With the current trend of 10 to 12 percent of vehicle imports per year, Kenya will have approximately 5 million vehicles registered by the year 2030 (Deloitte, 2016).

2.3 Motor Vehicle Registration

Vehicle registration is the process of adding a vehicle to a Motor Vehicle Register (MVR) by capturing the vehicle particulars such as type of vehicle, make of vehicle and vehicle owner’s details (James, Ansa, & Udoeka, 2016). This is done by a Motor Vehicle Administration (MVA) which has jurisdiction over a variety of activities related to the ownership and operation of motor vehicles, including the registration and titling of vehicles (Smith, et al., 2017).

According to (Kenduiwo, 2015) the Registrar of Motor Vehicles in Kenya, a department of KRA was the official repository of vehicle registration data but National Transport and Safety Authority (NTSA) has assumed most if not all of its mandate of vehicle registration (NTSA, 2017).

Importance of Motor Vehicle Registration

Several government authorities rely on accurate vehicle registration details. These departments include the tax authority that use the information for collection of vehicle related taxes, the security department for investigating vehicle-related and vehicle-assisted crimes, checking status of vehicle ownership, credentials, motor and road taxes as well as the highways authorities that need vehicle data as the basis for proper planning of road and highway networks, road maintenance and traffic control (Trucking Policy, 2017).

Registration details of a vehicle may be used to punish rogue drivers who may be found over speeding or driving under the influence of alcohol (Styslinger & Krafft, 2016). This may include suspension of the accused driver's license.

Selling or transfer of a vehicle to a customer only happens when the seller transfers ownership to the buyer by changing ownership details in the Motor Vehicle Register (Maryland Department of Transportation, 2017). This only happens when a record of the vehicle being sold exists in the Motor Vehicle Register (MVR).

2.4 Challenges Faced by Existing Vehicle Registration Models

One of the existing problems associated with current vehicle registration system is multiple registrations. This is a situation where vehicle owners who are in possession of multiple vehicles repeat the entire registration process. The repetition of entire registration process is also applicable to vehicle renewal process as well as newly purchased vehicles. It is envisaged that this repeated process could lead to redundancy in the vehicle registration system's database (James, Ansa, & Udoeka, 2016).

There is great variance in the content and format of vehicle registration documents across jurisdictions. This inconsistency hinders the ability of various stakeholders to locate and use the information necessary to perform their functions in an efficient manner. Inconsistencies in the data elements and document design make it difficult for the Motor Vehicle Administration (MVA) front line staff to quickly determine the vehicle and owner information when they are registering vehicles that were previously registered (American Association of Motor Vehicle Administrators, 2013).

Another problem is the inability to track fraudulent transactions that lead to unauthorised change of the car ownership details in MVR. This happens when a vehicle owner upon transferring the car ownership to a new buyer, can still tamper with the records in the MVR and change the car ownership to a third party who happens not to own the car for malicious intentions. These fraudulent transactions within the system happen without being detected (Pierro, 2017).

2.5 Blockchain Technology

A blockchain is a distributed and decentralised ledger containing connected blocks of transactions which guarantees tamper-proof storage of approved transactions (Samaniego, Jamsrandorj, & Deters, 2016).

2.5.1 How Blockchain Works

Blockchain seeks to establish trust in a distributed system. It creates a distributed storage of timestamped block of data where no party can modify the data contents or timestamps without being detected (Pierro, 2017). If a party creates a digital signature for a document, it establishes only a verifiable link between the party and the document. The existence of a valid digital signature proves that the party indeed intended to sign the document and that the document has not been altered. The digital signature guarantees nothing about the time when the document was signed but the timestamp requires trust in the party that signed it.

The fundamental concept behind the blockchain is that of tamper-proof storage of approved transactions. Valid or verified transactions are stored in the form of a block or lists of transactions that is linked to the previous one. A blockchain starts with an initial block. Upon creation of a new block the hash value of the preceding block is entered. Once a new block is formed, any changes to a previous block would result in a different hash code and would thus be immediately visible to all participants in the blockchain (Samaniego, Jamsrandorj, & Deters, 2016). This concept is referred to as immutability of data records where recorded data cannot be manipulated or modified once it is accepted in the blockchain network (Hofmann, Wurster, Ron, & Schwafert, 2018). Figure 2.1 shows an illustration of how blockchain works with the Merkle root or tree as a data structure where each layer is a combination of hashes from its child layer. In general, a Merkle tree is represented using a binary hash tree with each node having at most two children. The branches are the hash of the combined hashes of the two children (Mukhopadhyay, 2018).

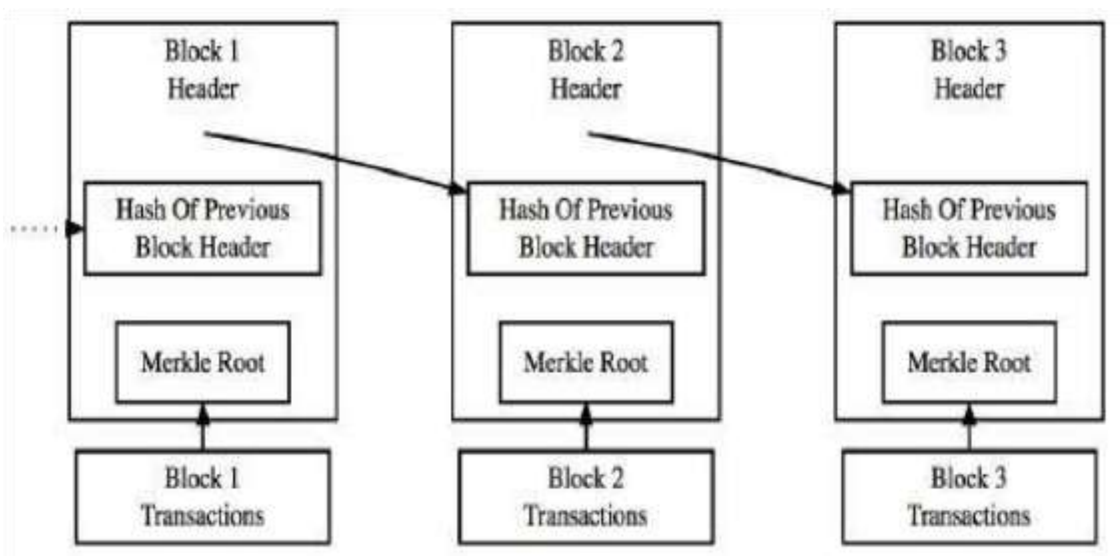

Figure 2.1: Blockchain Illustration *(Hanifatunnisa & Rahardjo, 2017)*

2.5.2 Types of Blockchain

There are several types of blockchain which can be grouped into:

Permission-less Blockchain: This includes Bitcoin and Ethereum, where all participants have the ability to write and participating in consensus to determine the block's validity (Hanifatunnisa & Rahardjo, 2017).

Permission Blockchain: This type of blockchain has known entities who assume control of the blockchain permission network. The blockchain permission system has mechanisms to identify parties that can control and update data together as well as controlling who can issue transactions (Hanifatunnisa & Rahardjo, 2017).

Private Blockchain: This is a special blockchain which has permission rights granted to a single entity and there exists only one domain trust (Hanifatunnisa & Rahardjo, 2017).

2.6 Business Blockchain Network

A business blockchain network is a decentralised network used for transfer of business assets between member organisations in the network. It uses distributed network technology for secure transfer of the assets which can either be tangible such as vehicles, farm produce or can either be digital such as records or music (Morris, et al., 2018).

Blockchain technology establishes trust through the use of distributed ledgers, smart contracts and consensus among participants of the network. The ledger contains the history of all transactions, current state of assets and transactions can only be added but not deleted. In the distributed ledger a transaction is triggered by the participant and it is recorded in an immutable block which is mainly a pool of data that contains other relevant information such as timestamps and their correct sequence (Miraz & Ali, 2018). Business rules that are used to validate transactions are agreed upon by member participants of the network and they help improve transaction processing speed, accountability and transparency within the network. This is known as consensus and it is encapsulated and executed by a chaincode or smart contract (Puthal, Malik, Mohanty, Kougianos, & Das, 2018). The smart contract is an application that contains the business logic and defines all the access to the ledger invoked by participants when querying or updating values of the assets (Miraz & Ali, 2018).

Furthermore, blockchain business networks ensure additional trust through provenance which means that the origin of any asset in the ledger in known and finality which guarantees each participant that their copy of the ledger matches that of other participants and that all their transactions are committed to the ledger successfully (Morris, et al., 2018).

2.7 Existing Motor Vehicle Registration Systems

Several motor vehicle registration systems are presented and analysed with focus being on the architecture while highlighting the similarities and differences. The limitations of these systems are also noted.

2.7.1 Motor Vehicle Registration System in India

This system was designed in India to capture vehicle details for registration and more importantly capture number plate of vehicles using cameras. The captured image is then used to retrieve information about the vehicle using the character segmentation technique implemented by the optical character recognition (OCR) algorithm. A traffic police can therefore apply a fine on a vehicle which has broken any traffic rule using the retrieved information of the vehicle.

The system is implemented both as a mobile-web application. The main challenge of this system is that it does not have a trail record of unauthorised modification of vehicle particulars. Anyone with access credentials can log in and change vehicle particulars undetected without consent from the vehicle owner (Tejas, Omkar , Rutuja, Prajakta, & Bhakti, 2017). Figure 2.2 shows the architecture of this system.

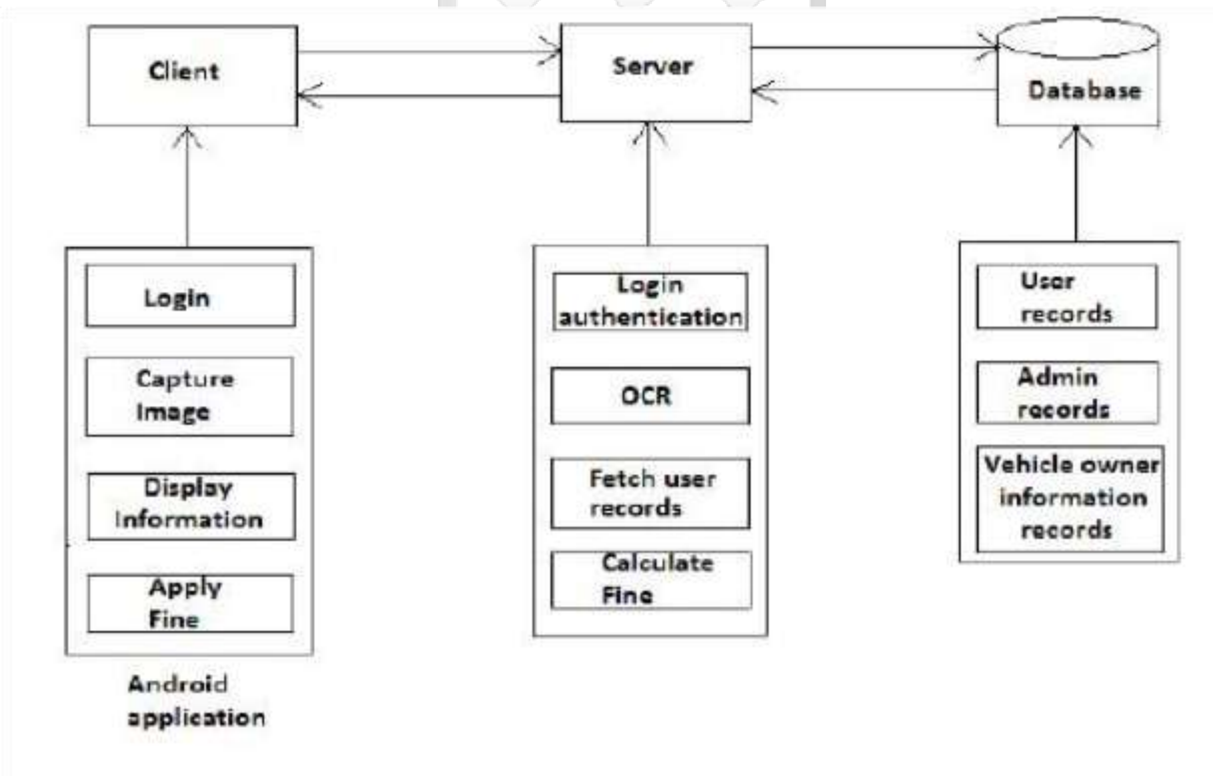

Figure 2.2: System Architecture

2.7.2 Motor Vehicle Registration System in Nigeria

This system was developed in Nigeria to aid in registration of motor vehicles. The system has a mobile-phone based interface which allows a customer to carry out registration using a mobile device and the registration details are stored directly into the State Board of Internal Revenue (SBIR) database. The web server serves as the point of entry to the website and any backend system that it might interface with. Vehicle owners or customers are able to supply their data and registration details at convenience provided they have internet access. At the end of a completed registration, a unique pin will be generated and will serve as the only authority that can allow easy access to the customer's account as well as an authorized administrator.

This will create a platform for a one stop registration transaction as shown in Figure 2.3. The main challenge with this system is that it is limited to only vehicle registration and therefore cannot scale to vehicle transfers that involves change of vehicle ownership and confirmation of ownership transfer (James, Ansa, & Udoeka, 2016).

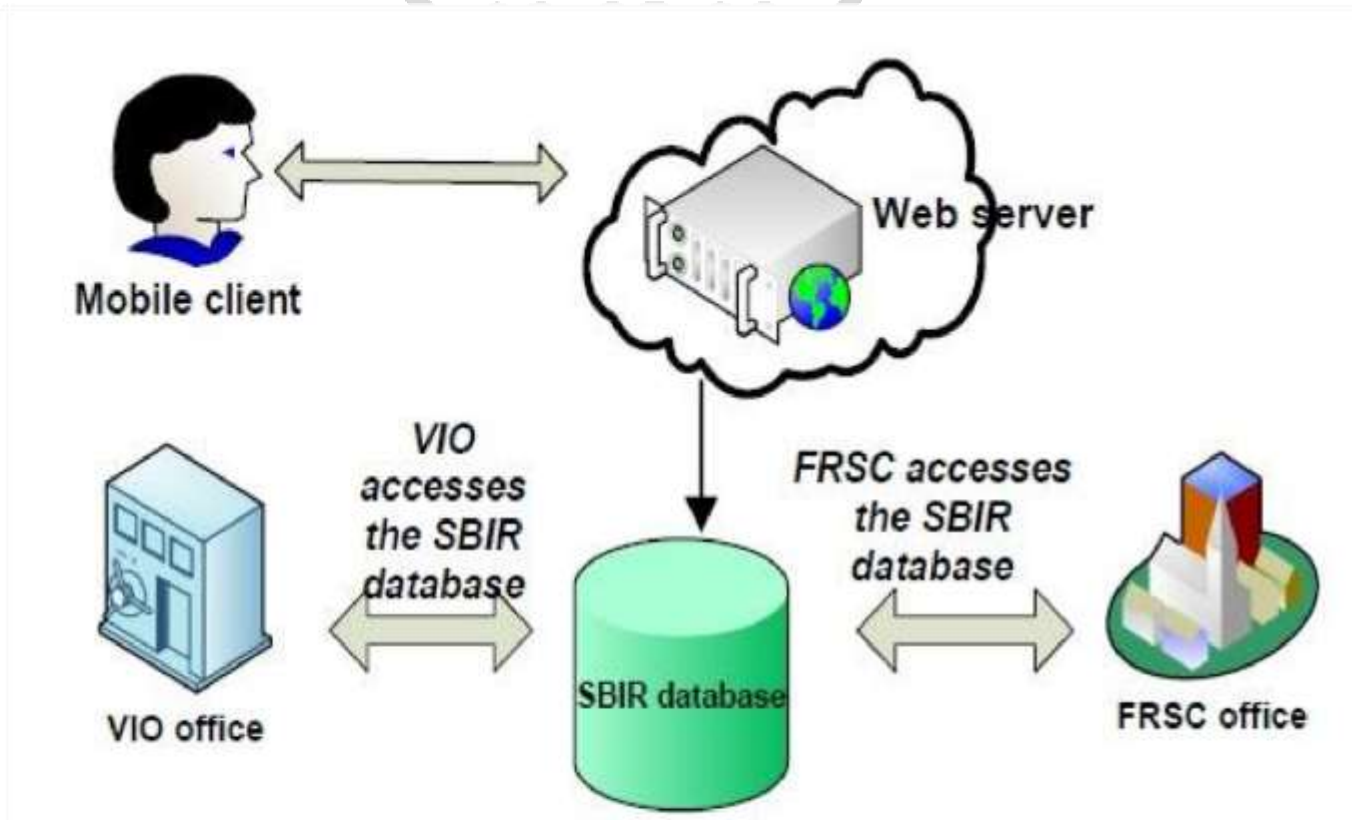

Figure 2.3: Motor Vehicle Registration System Architecture *(James, Ansa, & Udoeka, 2016).*

2.7.3 Motor Vehicle Registration System in Kenya

Vehicle registration is done by the National Transport and Safety Authority (NTSA). There is the option of registering as an individual, dealer, agent, financial institution or company. The services offered include car registration, transfer of car ownership, change of particulars, duplicate logbook application, reflective number plate application, vehicle inspection and online car search (NTSA, 2017). The main challenge is that the system can be highly tampered by unauthorised users and vehicle ownership details transferred to an unauthorised owner for malicious gain with the system not being able to record the fraudulent transactions. This has happened in the recent past where a number of cases have surfaced in that a legal car owner is confronted by another person claiming ownership of the same vehicle. This has been made possible by the fact that some unauthorised persons are able to access the system and change original vehicle ownership details in the system without being detected (Musambi, 2018). Figure 2.4 shows the system used by NTSA in the registration, transfer and confirmation of vehicle ownership transfer.

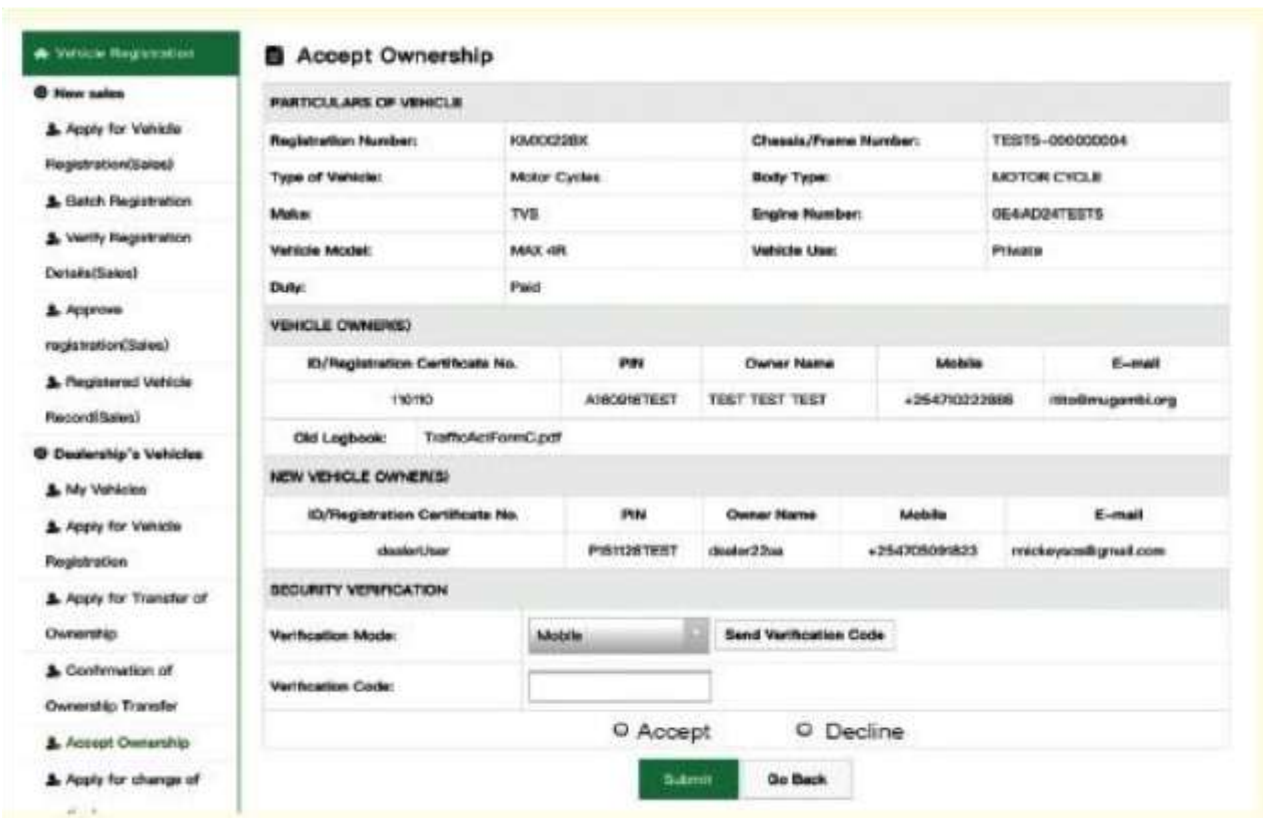

Figure 2.4: Transport Integrated Management System *(NTSA, 2017)*

2.7.4 A Blockchain Use Case for Car Registration

This study proposed development of a blockchain application known as BCar. The main functionalities of the system were registering a vehicle, changing ownership status and registering a leasing contract between a lessee and lessor (Rosado, Vasconcelos, & Correia, 2018). The main challenge of this application was that there was no mechanism of how a vehicle history could be tracked and therefore past vehicle owner(s) could not be identified by the system.

2.7.5 A Novel Public Blockchain-based Motor Vehicle History Reporting System

This work proposed a distributed blockchain motor vehicle reporting system known as CarChain. The system enabled car owners, car sellers, mechanics, insurance companies and governments to be able to view the vehicle owner's history as well as enabling vehicle ownership transfer.

The main challenge was that the system was not constructed based on any of the popular well known public blockchains. Instead a new framework was used that constructed a peer-to-peer overlay network that broadcasts transactions as any end multi-casting system in peer-to-peer live streaming applications (Masoud, Jaradat, Jannoud, & Zaidan, 2019).

2.8 Existing Blockchain Based Solutions in the Motor Vehicle Industry

2.8.1 Automotive Security and Privacy

According to Dorri, Steger, Kanhere and Jurdak (2017) interconnected vehicles offer a range of sophisticated services which benefit vehicle owners, manufacturers, transport authorities and other relevant industry players. This however, exposes the smart vehicles to a range of security and privacy threats like location tracking of the vehicles and or the remote tracking of the vehicles.

A blockchain-based architecture is proposed to protect the privacy of the vehicle owners and enhance security of the vehicular ecosystem. This is done by equipping each vehicle with an in-vehicle storage for storing privacy data. The vehicle owner then determines the information to be provided to third parties and what is stored in the in storage of the vehicle.

2.8.2 Digital Twin

A digital twin is a dynamic, digital representation of a physical asset that enables companies to track the past, current and future performance of an asset through its lifecycle. Groupe Renault in collaboration with Microsoft and Viseo have created a prototype that uses blockchain to connect new vehicles' maintenance details to its digital twin thus ensuring the data is fully visible and traceable to authorised parties such as vehicle owners.

The blockchain-based system ensures vehicles' maintenance history remains connected to the vehicle even when there is a change of vehicle ownership (Kückelhaus , Chung, Peralta, & Turner, 2018).

2.9 Blockchain Based Platforms

2.9.1 Hyperledger

Hyperledger Fabric

Hyperledger Fabric is a business blockchain framework used for deploying blockchain networks. It uses Fabric protocols to maintain the ledger, smart contracts and consensus between members of the network. It is designed for business use cases and can only be operated by a set of known participants meaning it is a permissioned blockchain. Being a permissioned blockchain, it provides a secure mechanism for interactions among the known entities of a network with common business interests and who want to maintain a decentralised network. Hyperledger Fabric leverages on container technology to host smart contracts or chaincode that comprise the application logic of the system (Morris, et al., 2018).

Hyperledger Composer

Hyperledger Composer is a set of tools for building blockchain business networks that accelerates and simplifies the creation of smart contracts and blockchain applications to solve business problems. It provides a convenience layer and business-level abstractions to be able to implement smart contracts on Hyperledger Fabric and also makes it easier to connect to the business network from a web or mobile application. Composer uses the Composer Modelling Language to define a business network which consists of participants, assets and transactions and then deploys the business network to Hyperledger Fabric (Morris, et al., 2018).

2.9.2 Ethereum

It is a public blockchain that uses the Turing complete built in programming language that provides an abstract layer allowing anyone to create their own ownership rules, transactions format and state transition functions (Dannen, 2017).

In Ethereum this is done through smart-contracts that are written using the Solidity programming language and also has the ability to save state meaning it can detect changes over time and be able to remember them over time. It also allows transactions such as the transfer of tokens known as Ether from one wallet to another (Mukhopadhyay, 2018).

2.9.3 NEO

It is an open source permissioned blockchain platform on which smart contracts and decentralised applications (Dapps) can be run. It aims at digitising assets and automating the management of these digital assets in order to create a smart economy, that is, an economy where parties can agree on a contract without the need of trust amongst one another. NEO has a native currency called

GAS which is a fee paid so that one can be allowed to utilise NEO's network and it is automatically generated for those who hold some sort of digital asset within the network (Houben & Snyers, 2018).

2.9.4 EOS

It is a blockchain and smart contract platform that focuses on speed, scalability and user experience. In order to achieve high throughput and zero transaction fees it uses delegated proof of stake (DPoS) and a token ownership bandwidth as its model.

Its architecture enables validating, governing and evolving a decentralised network in addition to human-readable account names, zero transaction fees and protocol level account recovery (Xu, Luthra, Cole, & Blakely, 2018).

2.9.5 Stellar

It is an open source distributed payments infrastructure which uses the Stellar Consensus Protocol (SCP) a construction for Federated Byzantine Agreement (FBA) and Lumen (XLM) as a crypto currency to pay for transactions on the Stellar network.

In addition, the Stellar network allows development of smart contracts on its network (Houben & Snyers, 2018).

2.10 Conclusions

The above mentioned blockchain platforms work best depending on the nature of the problem to be solved. According to Androulaki, et al., (2018) Hyperledger Fabric is an enterprise-grade, permissioned, distributed ledger technology platform for use in enterprise contexts. This means Hyperledger Fabric offers features that are required or essential in enterprise applications. It creates a permissioned network meaning that not everyone can use the network and therefore participants have to be known and verified.

In the case of the vehicle ownership tracking, only the relevant participants will be members of the network and this include NTSA, Motor Vehicle Agents and the Vehicle Owners. The network will have the assets to be transacted and the transactions to be performed by the participants. In addition, the network grants access control rights to the participants on what assets and transactions they can have access to. Hyperledger Fabric is best suited to be used to develop the blockchain network since it enables the development of a business network that meets all the above requirements.

Chapter Three: Research Methodology

3.1 Overview

The literature review covers the challenges faced when keeping track of vehicle registration and ownership transfer. It further reviewed the existing systems used for vehicle registration and their loop holes. Blockchain as a technology was discussed and proposed as a solution to address the existing gaps.

The first objective which seeks to identify the challenges faced when keeping track of vehicle ownership after they are registered is achieved in the literature review covered in Chapter Two by reviewing existing vehicle registration models.

The second objective which reviewed the existing vehicle registration models and the challenges they faced was addressed by evaluating related works in the literature review in Chapter Two.

The third objective which is to design, develop and test a blockchain-based solution for vehicle registration was achieved through the software development methodology that was covered later in section 3.2 in this chapter.

The fourth objective which is validating the effectiveness of the solution was covered in the validation section 3.3 of this chapter.

3.2 Software Development Methodology

In order to address the gaps in existing vehicle registration models, this study sought to adopt a development methodology commonly known as Software Development Life Cycle (SDLC) and more specifically the Agile SDLC (Rastogi, 2015).

Agile model works by handling project requirements differently and the existing methods were tailored so as to best suit these project requirements. Tasks were therefore divided into time frames for delivery of specific features for a release using iterative approach. A working product was delivered after every iteration and a product was incremental after every release in terms of features with the final product holding all the features required by the customer as illustrated by the Figure 3.1 (Altexsoft, 2016).

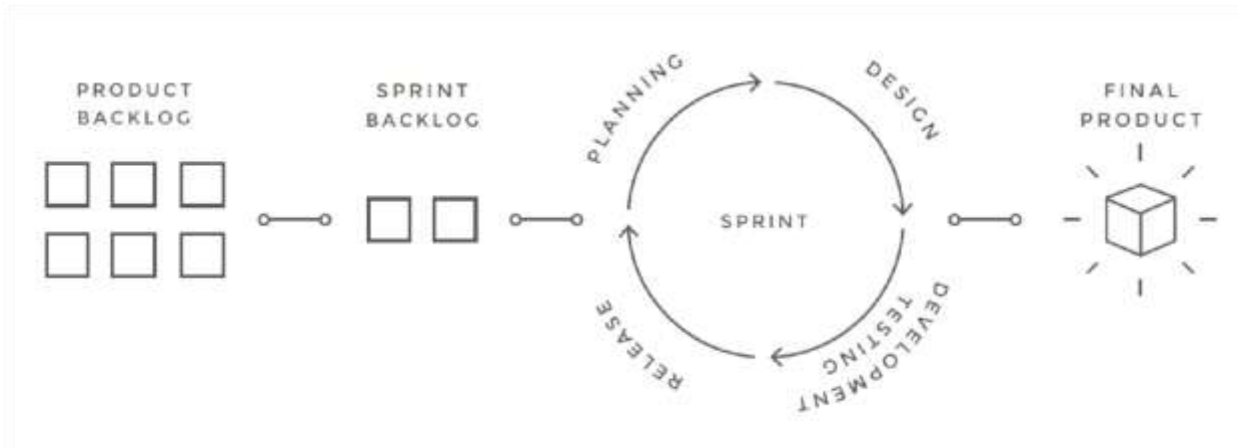

Figure 3.1: Graphical Representation of the Agile Model *(Altexsoft, 2016)*

According to Altexsoft (2016), these stages entail:

3.2.1 Planning Phase

This was the first stage of the Agile Software Development Life Cycle. The relevant stakeholders of the system were identified and the literature covered in the previous chapter was analysed to determine the gaps in the existing system. A questionnaire to find out the needs of vehicle owners was issued as shown in Appendix A. The information gathered helped in formulating requirements for the proposed system. In addition, the development environment which includes the IDE and other software tools was set up during this phase. The target population was private vehicle owners within Nairobi and who number approximately 1,497,224 (Kenya National Bureau of Statistics, 2019). The study was within Nairobi due to its proximity to the researcher. According to (Singh & Masuku (2014) the sample size was arrived at from a formula recommended by Taro Yamane which is as follows:

n = N/ (1+N (e) 2).

n refers to the sample size.

N refers to the population size. e refers to the margin of error.

The population was 1,497,224, the margin of error is 10% and this resulted to a sample size of approximately 100.

3.2.2 Designing the Product Architecture

The requirements gathered were used as the reference point by product architects to come up with a design for the blockchain prototype to be developed.

Unified Modelling Language (UML) tools according to Kendall and Kendall (2014) were used for modelling of the system through design diagrams that offer clarity on how the system requirements were implemented.

Use Case diagrams as discussed by Klimek and Szwed (2010) was used for system functionality. This involved identifying the use cases and actors of the system. The actors were the vehicle authorities such as NTSA, vehicle agencies as well as the vehicle owners. The use cases were the transactions performed by the actors like vehicle registration, transfer of vehicle ownership as well confirmation of vehicle ownership. System Sequence Diagrams as elaborated by Minhas, Qazi, Shahzadi and Ghafoor (2015) was used to illustrate data flow among the different entities. According to Kendall and Kendall (2014) the balsamic tool was used to create a wireframe that will mimic the flow of both the mobile and web solution. The mockups gave a clear view of how the interfaces will be and their user experience. This included showing the interfaces that users use to create transactions and commit them to the blockchain both on the mobile and web platforms. In addition, participants could query the blockchain and the information read displayed on the web and mobile interfaces developed.

The blockchain design had four logical layers as shown in Figure 3.2.

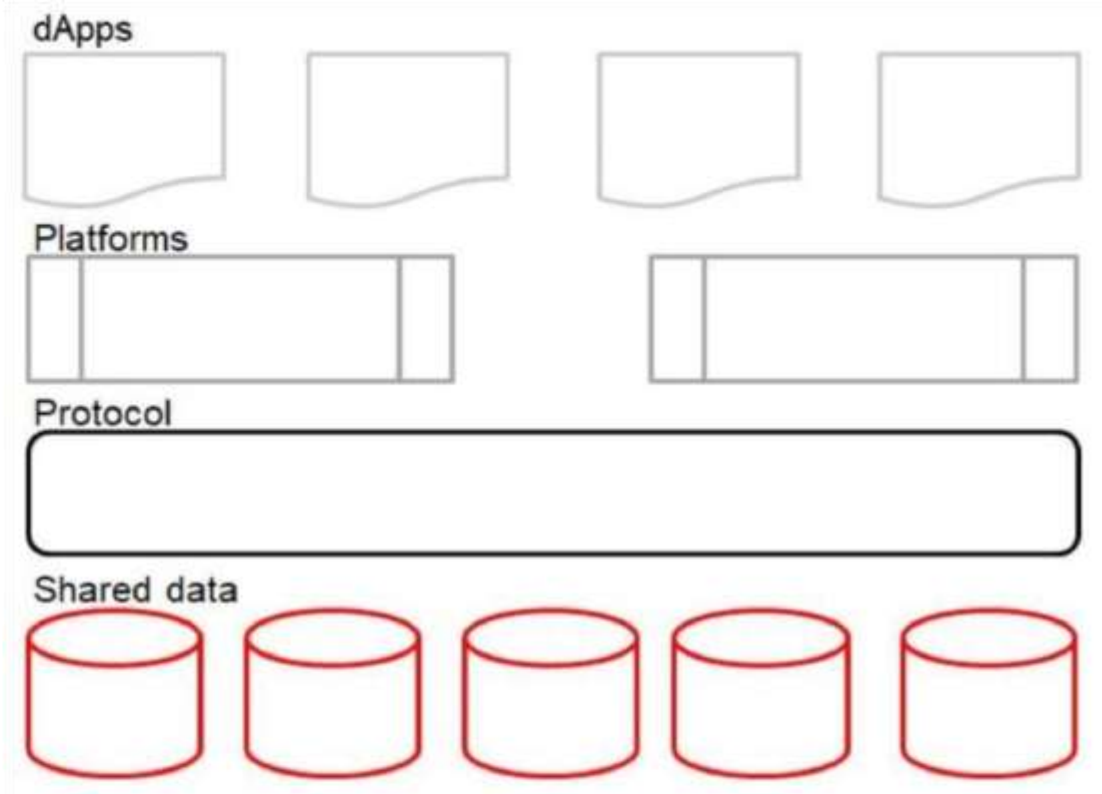

Figure 3.2: The Blockchain Technology Stack

Shared Data: Hyperledger Fabric was used as the decentralised database that stores all the transactions between the participants of the blockchain business network. The data that was to be shared is a contract between the participants involving an asset(s) (Cachin, 2016).

Protocols: Hyperledger Fabric was the framework which implemented rules for consensus, validation, and participation. The fabric's peer-to-peer communication was done by Protocol Buffers which serialized data structures for data transfer between peers (Androulaki, et al., 2018). Protocol buffers are a language-neutral, platform-neutral and extensible mechanism for serializing structured data.

Platforms: Platforms are a kind of middleware that allowed developers to build applications on top of protocols. Platforms were used to develop the blockchain application which incorporates smart-contracts and the Assets, Participants and Transactions involved in the blockchain network (Morris, et al., 2018).

Table 3.1: Business Network Definition

Participants	Authority(NTSA), Vehicle Owners, Vehicle Agencies
Assets	Vehicle
Transactions	CreateVehicle, TransferVehicle, ConfirmOwnership

Products: Products are the interface to the protocols and platforms. Examples of products are dApps (Decentralized Applications). They allowed users to interact with the protocol and the shared data. A mobile and web application was built and they utilised blockchain technology alongside platform capabilities like smart contracts to provide not only the security of the blockchain, but also the ability to self-execute operations.

3.2.3 Building the Product

The study came up with a blockchain business network that was developed using the Hyperledger Fabric (Hyperledger, 2019). Hyperledger Fabric was used to develop the blockchain network (Puthal, Malik, Mohanty, Kougianos, & Das, 2018). Golang programming language was used to define the assets, participants and transactions of the blockchain network (Hyperledger, 2019). Smart contracts were developed to implement the business logic that included defining the asset(s) to be transacted among participants and all the transactions that involved an asset(s). A chaincode developed was used to contain all these coded-up logic of the agreements between the participants before they were committed to the ledger. These was done using the Golang programming language. A RESTful API which is an architectural style and approach to communications with code that allows two software programs to communicate with each other, was generated to interface the blockchain network to the mobile and web application thus connecting the two to the blockchain network. The web application was developed using the AngularJS framework. The mobile application was developed on the Android platform.

The blockchain network once developed was brought up using Docker containers which was used for deploying the Hyperledger Fabric blockchain network either on a local machine or remotely (Androulaki, et al., 2018).

3.2.4 Testing the Product

This stage was a subset of every stage since testing has to be performed at each and every stage. The proposed system had to undergo a series of tests to ascertain viability of the expected outcome. The main tests included:

Functional and Non-Functional Testing: This was done to test the systems' functional and non-functional requirements. According to Khan, Srivastava and Pandey (2016) Behaviour Driven Development was used as the testing method. Automated scripts for unit testing were written and this worked by providing appropriate input, verifying the output and comparing the actual results with the expected results. The scripts tested functions like vehicle registration, transfer and confirmation of ownership transfer as well as the performance and security of the application.

Usability Testing: This was done to determine the usability of the developed application by using the Acceptance Test Driven Development (Khan, Srivastava, & Pandey, 2016). Users were asked to complete tasks such as registering, transferring and accepting vehicle ownership transfer while they are being observed by the researcher. The input from users of the system was collected, used to develop acceptance criteria, translated that criteria into manual or automated acceptance tests and then developed code against those tests. This helped minimise the need to re-design features in new releases since the feedback is from the users directly.

Compatibility Testing: The system was tested on the different Android and web-based platforms as well as different browsers to ensure it functioned as expected. The mobile application was tested using the Firebase's Testlab to verify its stability across the different Android versions (Khawas & Shah, 2018).

3.3 Validation

To validate that the application developed addressed the challenge of tracking vehicle ownership history a questionnaire was sent to the Authority as shown in Appendix B. The questionnaire sought to find out whether the solution addressed the stated loop-holes. The solution primarily focused on having all the transactions related to the vehicle asset being committed on an immutable ledger.

3.4 Ethical Measures

Information consent and confidentiality was enforced on vehicle owners' information gathered either through interviews or questionnaires. Consent from the relevant authorities was sought out in order to use the information gathered for purposes of the research and the researcher was also required to sign an agreement to this effect.

Chapter Four: System Design

4.1 Overview

This chapter discussed the system design and architecture of both the front-end and back-end of the application and the design tools required for implementation of the application. The requirements gathered in the planning phase as discussed under section 3.2 of chapter three and using a questionnaire as shown in Appendix A captured the information required in vehicle registration, vehicle transfer and confirmation of vehicle ownership transfer and this information was then used to design the system appropriately. It therefore involved use of Context Diagrams, Sequence Diagrams and Use-case Diagrams that detailed how the system works.

It was mandatory to have the requirements gathered since they were used by the software engineer in this case the researcher, as a guide in coming up with the design of the blockchain prototype. The design was implemented using the Unified Modelling Language (UML) with tools that are discussed in the prior paragraph. The design tools according to Kendall and Kendall (2014) gave clarity on the flow of the system functionalities and how it was implemented in chapter five.

4.2 Requirement Analysis

This section discussed the functional and non-functional requirements of the system that was developed.

4.2.1 Functional Requirements

Functional requirements referred to the critical functions performed by the system that enabled the researcher meet the research objectives. The functions performed by each participant were as follows:

Authority/NTSA

i) Vehicle registration: The system should allow the MVA to register a new vehicle on behalf of the owner.

ii) Vehicle history information: The system should allow the MVA to keep track of the vehicles transfer to different owners. This includes the particulars of the vehicles and the timestamp of when it was created.

Agents

i) Vehicle registration: The system should allow the dealers to register vehicles in their possession or on behalf of the owners who have bought vehicles.

ii) Vehicle transfer: The system should be able to allow transfer of vehicles owned by the agencies to the new owners who have bought them.

iii) Vehicle history: The system should allow the agent to view all the owners of the vehicle at different times.

Vehicle Owners

i) Vehicle registration: Once a vehicle has been bought the new owner should be able to register the vehicle(s) in the system.

ii) Vehicle transfer: Vehicle owners should be able to transfer the vehicle to new owners who have bought them.

iii) Transfer ownership confirmation: Once a vehicle has been transferred, the new owner should be able to acknowledge receipt after which the transaction is committed to the blockchain.

iv) Vehicle history: The system should allow the owner to view prior owners of the vehicle if they indeed existed.

4.2.2 Non-Functional Requirements

These requirements referred to the criteria that was used to measure or judge the operation of the developed system rather than the specific functions it performed. These included:

Connectivity: The system had to be connected to the internet to enable communication between the frontend and the backend functionalities.

Capacity: The system had to support the traffic to and from the system and it therefore meant it had to be elastic to accommodate the increasing number of users into the system.

Performance: The system had to ensure minimal time in relaying requests and responses back to the users of the system. This applied to both front-end requests and back-end responses of the system.

Usability: The system should have an interface that is friendly and easy to interact with.

4.3 System Architecture

Blockchain technology was used for implementation of the design requirements which included a distributed ledger and a way of validating transactions on the distributed ledger.

The blockchain technology was implemented on the Hyperledger Fabric framework which is a permissioned blockchain where the participants are all known to one another and verified (Androulaki, et al., 2018). In this case the blockchain network had three participants namely *Authority (NTSA), Agents* and *Owners*. The vehicle with its relevant details was the asset that was being transacted among the participants on the blockchain network. The main transactions were vehicle registration, vehicle transfer and confirmation of vehicle ownership transfer.

The Hyperledger Fabric architecture is as shown in the Figure 4.1.

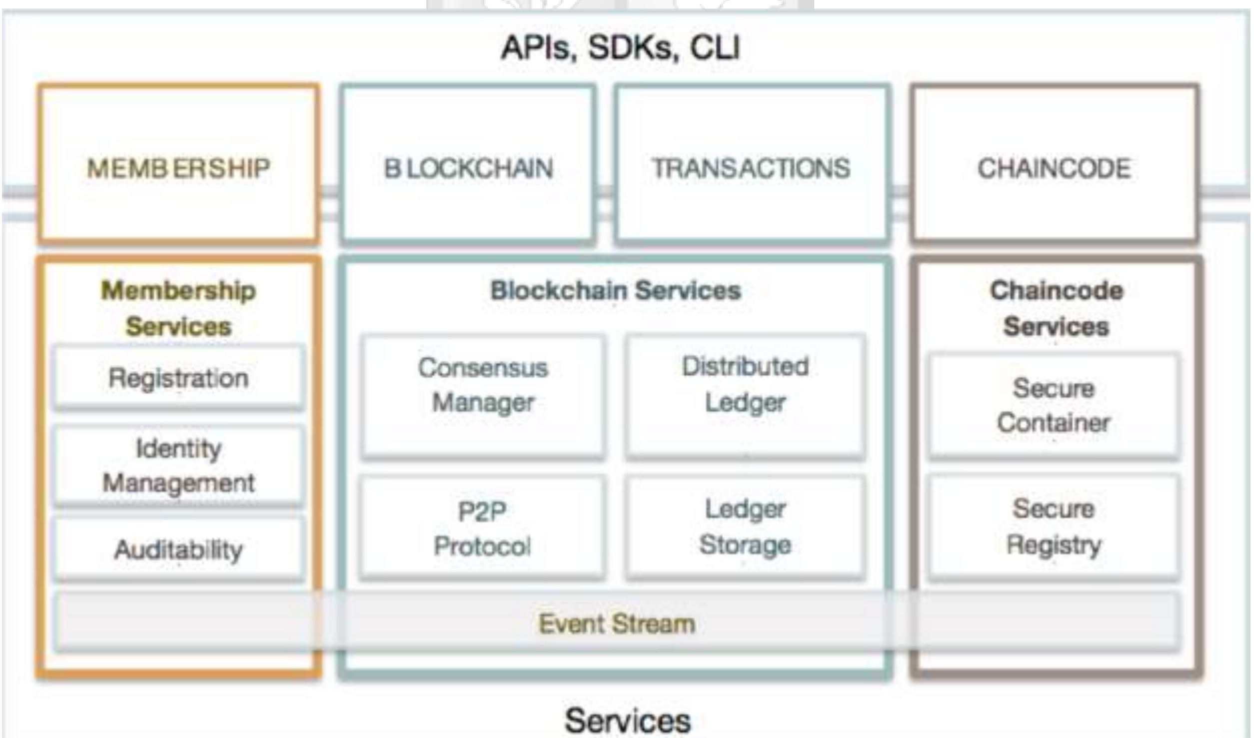

Figure 4.1: Hyperledger Fabric Architecture

4.3.1 Membership Service Provider

All the participating nodes in this blockchain network, that is, the Authority, Agents and Owners have to be verified and this is done using the Membership Service Provider (Cachin, 2016). The participating nodes have a unique digital identity which is used by the Membership Service Provider to determine which nodes can participate (Androulaki, et al., 2018). The unique digital identity is created using a public key infrastructure that is a public and a private key pair in order to associate a unique digital identity with each peer. The private key is what the peer will use to sign transactions, so that transactions can be verified as having originated from a particular known peer. All the peers on this network will have access to a public channel and there will be a shared ledger associated with this public channel that all of these nodes can update.

4.3.2 Transactions

Transactions or smart contracts are implemented using chaincode which is a self-contained program that runs on the blockchain network. Chaincode contains the coded-up logic of the agreements between the Authority, Agents and Owners who are the participants of this blockchain network. The main transactions are registration of a vehicle, vehicle transfer and confirmation of vehicle ownership transfer. The chaincode in this network is implemented using the Golang programming language.

Transactions in this blockchain network follow a lifecycle with three sequential phases:

Execution Phase

This is where the chaincode for smart contracts are executed and all the transactions (as mentioned above) in a particular block can be executed in parallel as well. Execution is performed by endorsing peers (Androulaki, et al., 2018). Once the transactions have been executed and endorsed, they are passed to an ordering service.

Ordering Phase

The ordering service or ordering nodes are responsible for arranging all of these transactions in some order using an ordering algorithm (Androulaki, et al., 2018). Only endorsed transactions need to be ordered and can only be added to the ledger if enough peers endorse the transactions. Once the transactions have been ordered they are then passed to validating peers or validating service.

Validating Phase

Each peer validates the transactions before committing them to the ledger. Validating peers is where the transactions are verified to ensure that they can be applied to the latest state of the ledger. Validating peers help check for issues such as double spending, ensuring the same asset in this case the vehicle is not to multiple participants at the same time.

The transaction flow in the blockchain network is as shown in Figure 4.2.

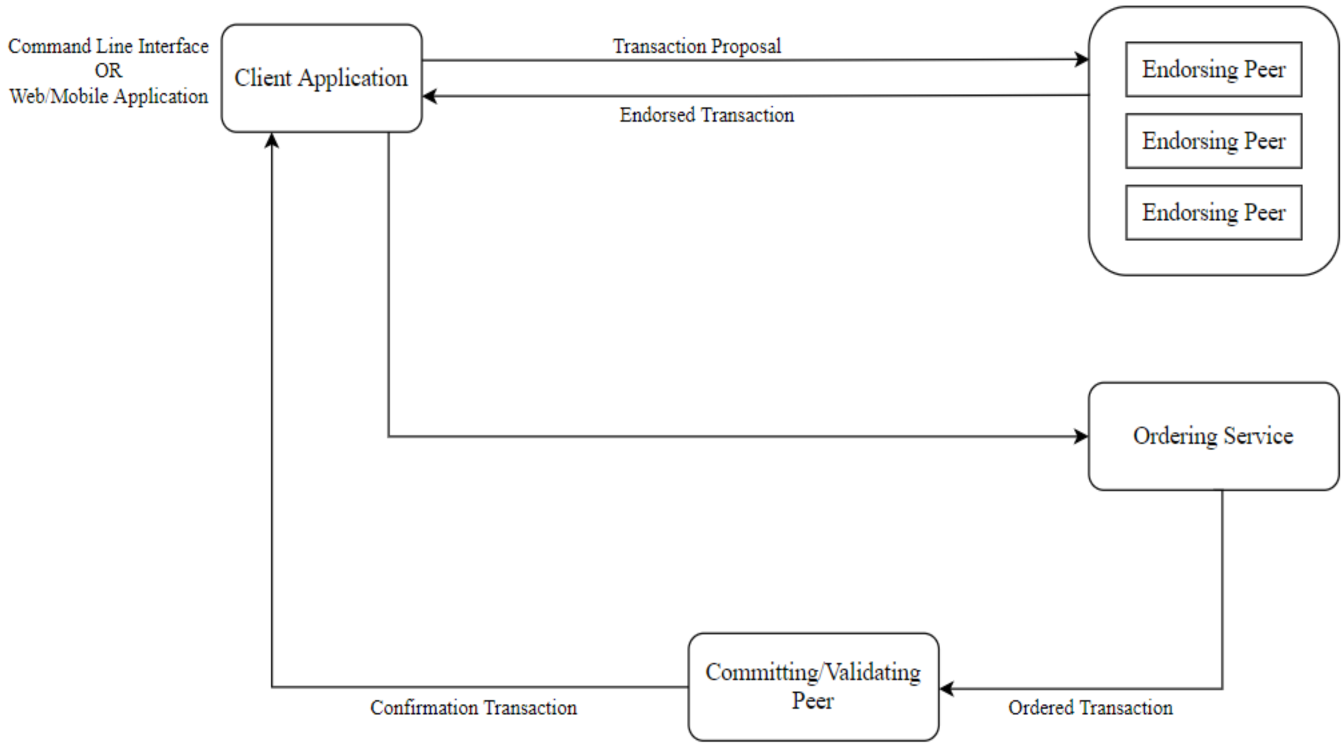

Figure 4.2: Transaction Flow on the Blockchain Network

The client application is responsible for interacting with peers on the blockchain network and executing the chaincode. In this case the client application is both the web application developed using the AngularJS framework and a mobile application developed on the Android platform. A RESTful API is developed which connects both the client application and the blockchain network and uses the JSON data format for consuming information on the client application. The web application will contain all the functionalities of the system and is accessed by all the three participants. However, the mobile application is only for vehicle owners and only allows viewing of owners' vehicles and querying the vehicles' history from the ledger. The API helps the client application to interact with the peers on the blockchain network by submitting a transaction proposal. A transaction proposal can be vehicle registration, vehicle transfer or confirmation of vehicle ownership transfer with its main parameters being the vehicle particulars such as owners full names, ID number, mobile number, date of birth, pin number, email address, vehicle plate number, vehicle type, vehicle make and vehicle model. A transaction proposal can be an *Invoke Transaction* which maybe writing the parameters, for example, vehicle registration or it can be *Query Transaction* which returns the state of an asset by reading directly from the ledger, for example, vehicle history. Once a transaction has been endorsed, ordered and validated it is then applied to the ledger and the state of the ledger updated.

4.3.3 The Ledger (Blockchain)

The ledger in this blockchain network is simply the blockchain itself. It represents the current state of the vehicle assets and all transactions performed using this asset. The vehicle asset is modelled in the form of key value pairs of the vehicle particulars mentioned above and these is what represents the current state of the asset. The ledger also contains all the state changes which involve the assets such as vehicle transfers and vehicle transfer ownership confirmations which is what is returned when the history of the vehicle is queried from the ledger.

4.3.4 Deploying the Blockchain Network

The blockchain network is brought up using Docker containers can run on either the local machine or a remote hosting service. The peers and orderers of the network will all be hosted in Docker containers. The chaincode is also hosted on the Docker containers which simplifies the management of the lifecycle for chaincode, that is, starting, stopping or aborting chaincode.

4.4 System Design Tools

Tools used to design the system included context diagram, use case diagram and sequence diagram as shown in the figures below.

4.4.1 Database Schema

The users of the system were authenticated using a relational database which contained the users' information, user roles and user types. Once authenticated into the system they could then have access to features of the system based on their roles and all transactions performed by them would be verified and committed into the ledger. The main transactions included vehicle registration, vehicle transfer and confirmation of ownership transfer. These three transactions were committed and stored onto a blockchain.

The Blockchain (The Ledger)

Once a user was authenticated into the system using a relational database as shown in Figure 4.3, they got access to the main functionalities of the system whose transactions were committed onto the ledger. These transactions involved an asset on the blockchain which in this was a vehicle. The ledger was structured as follows:

Vehicle Particulars: These were the details of the vehicle being registered and they captured the:

reg_id - vehicle registration number

vehicle_make – make of the vehicle.

vehicle_model – model of the vehicle.

vehicle_make – make of the vehicle.

Vehicle Owner Details: These were details of the vehicle owner. Once a user logs into the system their personal details were captured. These details would be used during registration of a vehicle by the user where they would be attached to a vehicle details to ensure the vehicle is registered under the user. These details would then be committed onto the blockchain. The details captured were:

name – full name of the vehicle owner.

id_number – national identification of the vehicle owner.

phone – mobile number of the vehicle owner.

email – email address of the vehicle owner.

pin – KRA pin number of the vehicle owner.

The vehicle particulars and vehicle owner details formed a block of transactions on the ledger which would be hashed and assigned a transaction number. This would make it easy to query for the owner of a particular vehicle and all past owner(s) of that vehicle. This study focused registering a vehicle, transferring it and confirming vehicle ownership transfer, thus the information captured was sufficient enough to perform these transactions on the blockchain. However, there was much more information needed to fully register a vehicle and this was to be part of the future work as discussed in section 7.3 of chapter seven. Figure 5.3 in chapter five showed the web application page that captured the vehicle particulars and vehicle owner details when doing a vehicle transfer transaction on the blockchain.

The Figure 4.3 is an Entity Relationship Diagram (ERD) that showed the database design of the system with the primary keys and the foreign keys of the tables and the kind of relationships between the tables. This is the relational database used for authentication of users into the system.

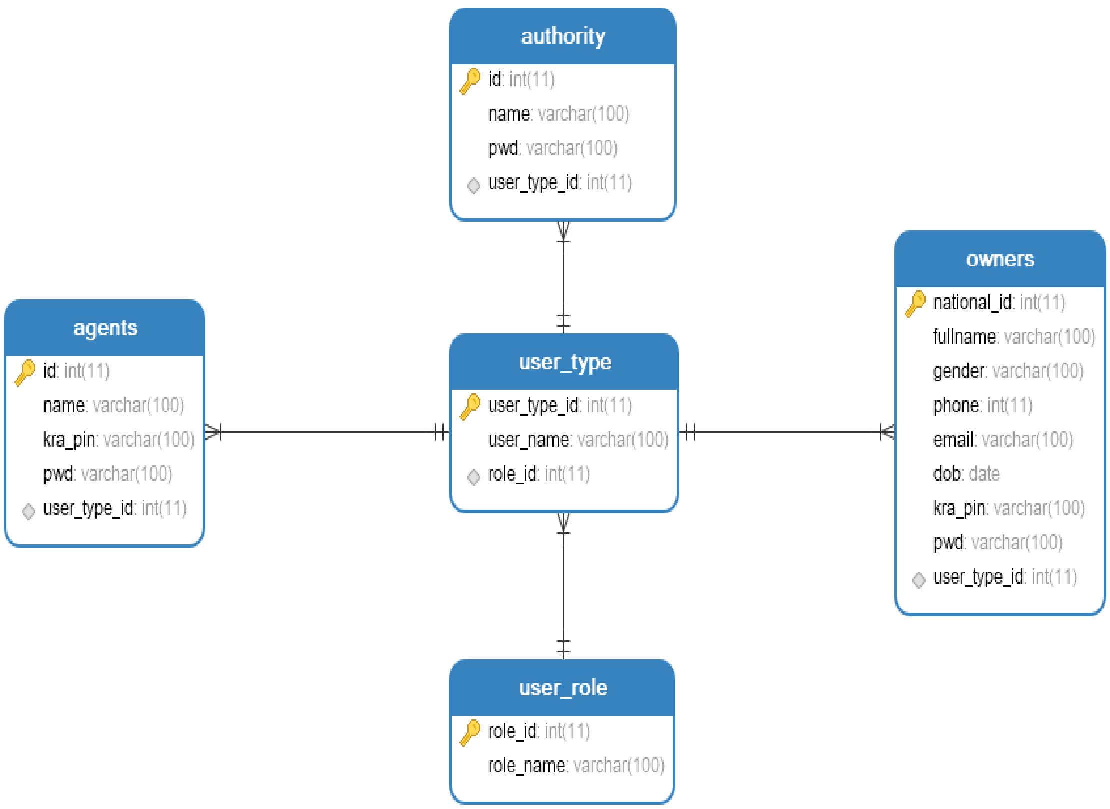

Figure 4.3: Entity Relationship Diagram

Database Tables

i) User Role Table

Table 4.1 contains users' role that are used during log in. A user's role is checked during log in and it is mapped to the user type to enable assignment of relevant roles to the user.

Table 4.1: User Role Table

Column Name	Data Type	Index
role_id	Integer(11)	Primary Key
role_name	Varchar (100)	

ii) User Type Table

Table 4.2 contains the user types of the participants of the system and the access roles of each user.

Table 4.2: User Type Table

Column Name	Data Type	Index
user_type_id	Integer(11)	Primary Key
user_name	Varchar (100)	
role_id	Integer(11)	Foreign Key

iii) Owners Table

Table 4.3 contains vehicle owners' details. Owners must first be registered before they can access the system functionalities.

Table 4.3: Vehicle Owners Table

Column Name	Data Type	Index
national_id	Integer(11)	Primary Key
fullname	Varchar (100)	

gender	Varchar (100)	
phone	Integer(11)	
email	Varchar(100)	
dob	Date	
kra_pin	Varchar(100)	
pwd	Varchar(100)	
user_type_id	Integer(11)	Foreign Key

iv) Authority Table

Table 4.4 contains the authority's details. It has credentials that are used by the Authority to log into the system.

Table 4.4: Authority Table

Column Name	Data Type	Index
id	Integer(11)	Primary Key
name	Varchar (100)	
pwd	Varchar (100)	
user_type_id	Integer(11)	Foreign Key

v) Agent Table

Table 4.5 contains details of the various agents. The log in credentials are checked from the table before the agents are allowed access into the system.

Table 4.5: Agents Table

Column Name	Data Type	Index
id	Integer(11)	Primary Key
name	Varchar (100)	
kra_pin	Varchar (100)	
pwd	Varchar (100)	
user_type_id	Integer(11)	Foreign Key

4.4.2 Context Diagram

The Figure 4.3 showed the context diagram of how the system participants interacted with the application. The Authority could create a transaction by registering vehicles into the blockchain and be able to track the vehicle ownership history. The Agents transactions on the blockchain are registering, transferring and tracking vehicle ownership history in the system. They also verify ownership of the vehicles before transfer. The Owners transactions on the blockchain include registering and transferring vehicles and confirming transfer ownership of vehicles assigned to them by other users. They need to verify the ownership of the vehicles before acknowledging receipt and they can as well track the vehicle ownership history from the blockchain.

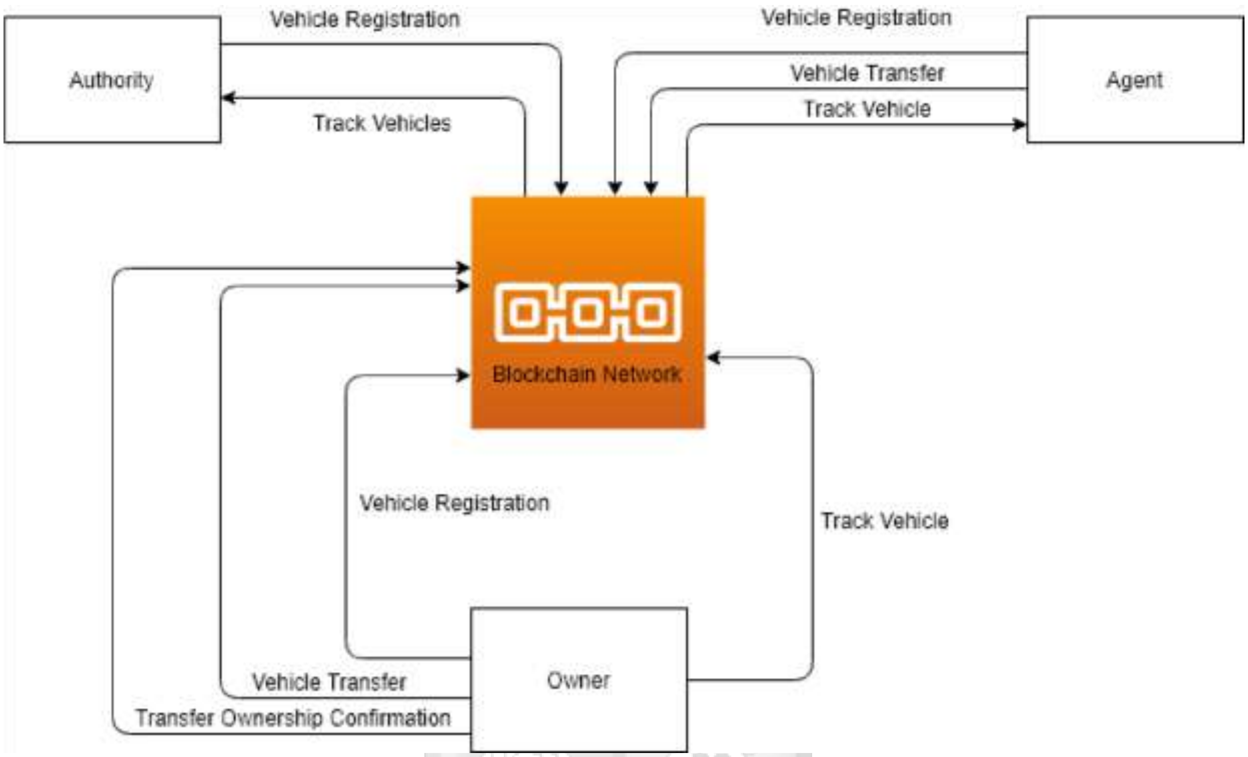

Figure 4.4: Context Diagram

4.4.3 Use Case Diagram

The use-case diagram showed the different actors who interacted with the system and their roles in the system as illustrated in Figure 4.4.

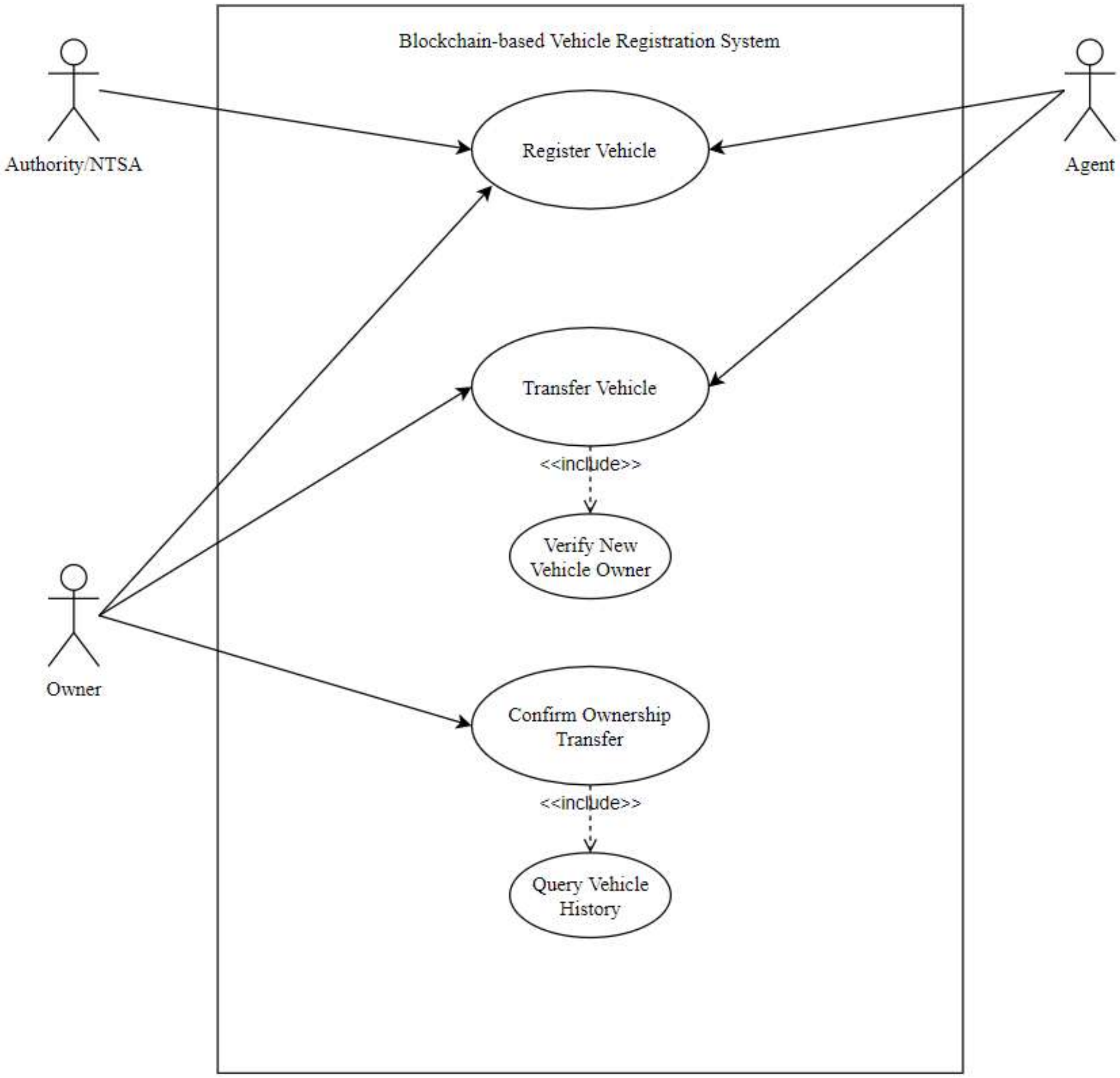

Figure 4.5: Use Case Diagram

Use Case Description

The use case description of how the various actors interact with the system is explained below.

Table 4.6: Vehicle Registration Use Case

Use Case 1: Register Vehicle.	
Use Case Description: The Authority should register the vehicle in the blockchain.	
Primary Actors: Authority.	
Precondition: The user must have the write access to the blockchain.	
Post condition: The user can initiate a transaction.	
Typical case of Events	
Actor Response 1. User initiates a vehicle registration transaction.	**System Response** 2. Vehicle registration details are committed to the blockchain.
Alternative flow Registration details are not committed to the blockchain.	

Table 4.7: Track History Use Case Description

Use case 2: Track History
Use case Description: This use case describes how to keep track of vehicle ownership history on the blockchain.

Primary Actors: Authority, Agent, Owner.	
Precondition: The user must be have read access right to the blockchain.	
Post condition: The user views vehicle ownership history.	
Typical case of events	
Actor Response	**System Response**
1. User queries the blockchain for vehicle ownership details.	2. System displays vehicle ownership history details. .
Alternative flow The user queries for a non-existent vehicle.	

Table 4.8: Transfer Vehicle Ownership Use Case Description

Use Case 3: Transfer Vehicle Ownership.
Use Case Description: The Agent or Owner transfers a vehicle.
Primary Actors: Agent, Owner.
Precondition: The user must have a vehicle registered under them in the blockchain.

Post condition: The user can initiate a transfer transaction of the vehicle.	
Typical case of Events	
Actor Response	**System Response**
1. User initiates a vehicle transfer request transaction. 3. The user initiates a transfer transaction.	2. The system verifies the vehicle ownership details and displays the vehicle details.
Alternative flow Transfer vehicle transaction is not committed to the blockchain.	

Table 4.9: Verify Vehicle Ownership Use Case Description

Use Case 4: Verify Vehicle Ownership.
Use Case Description: The Agent or Owner verifies vehicle ownership before issuing a vehicle transfers.
Primary Actors: Agent, Owner.
Precondition: The user must have a read and write access rights to the blockchain.
Post condition: The user verifies the vehicle ownership.

Typical case of Events	
Actor Response	**System Response**
1. User queries the blockchain to verify ownership details.	2. The system verifies the vehicle ownership details and displays the vehicle details.
Alternative flow User query is not submitted to the blockchain.	

Table 4.10: Confirm Ownership Transfer

Use Case 5: Confirm Ownership Transfer.
Use Case Description: The Owner acknowledges receipt of a vehicle transfer.
Primary Actors: Owner.
Precondition: The user must have a vehicle transferred to them on the blockchain.
Post condition: The user acknowledges receipt of the vehicle ownership.
Typical case of Events

Actor Response	System Response
1. User queries the blockchain to verify ownership details. 3. The user acknowledges receipt and the transaction is committed to the blockchain.	2. The system verifies the vehicle ownership details and displays the vehicle details.
Alternative flow Transfer ownership confirmation is not committed to the blockchain.	

4.4.4 Sequence Diagram

The sequence diagram showed the processes that occurred within the system as illustrated in Figure 4.5.

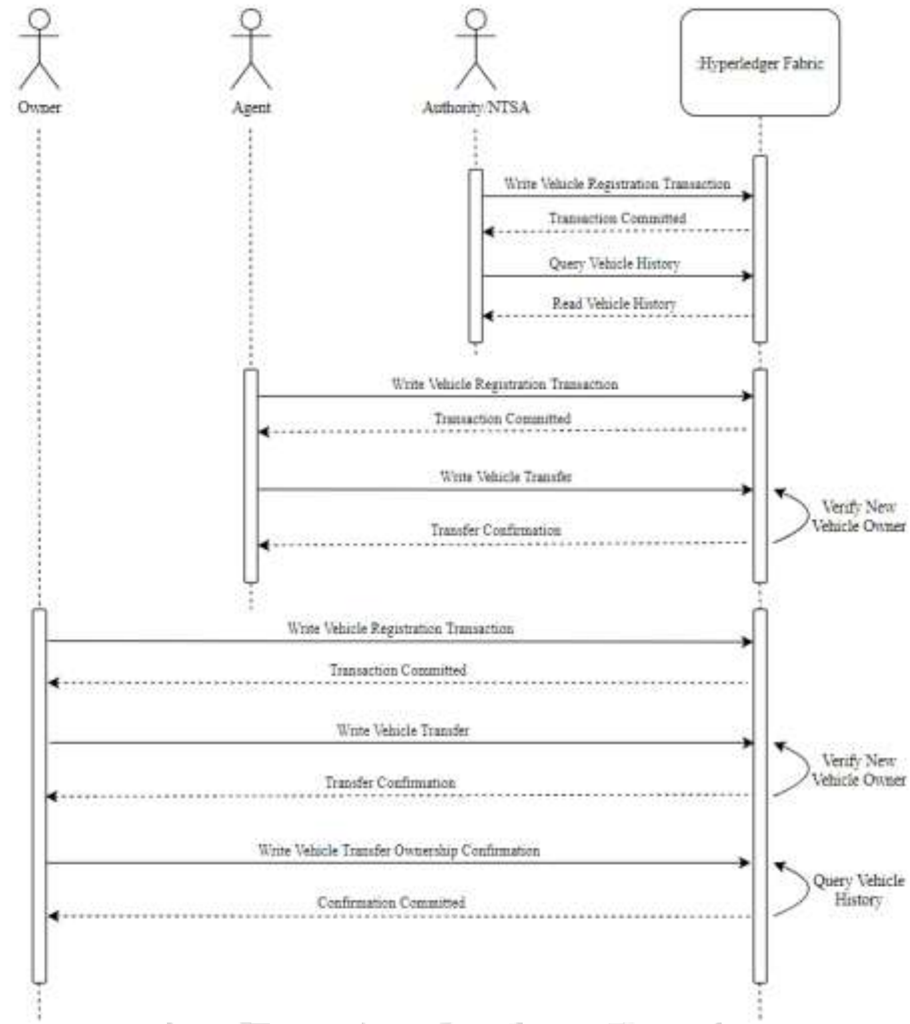

Figure 4.6: Sequence Diagram

4.5 Wireframe Diagrams

This section dealt with the flow of screen presentation which include mobile application wireframes.

4.5.1 Mobile Application Wireframes

This first screen was the login page which enabled the Owner to login into the system and view their vehicle(s) details. There was also a link to the registration page for registering new users. The log in and register screens are as shown in Appendix C.

Once the user was logged into the system then they could be able to view their vehicles as shown in Figure 4.7.

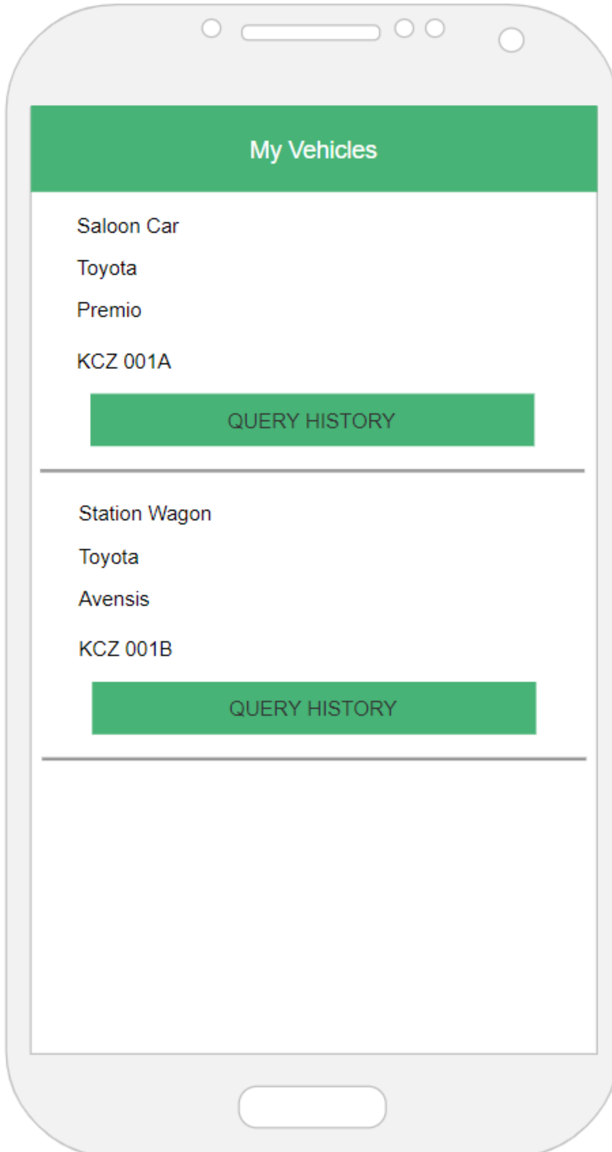

Figure 4.7: Vehicle Details Screen

The vehicles details page also enabled querying of a vehicle's history information by clicking on the query history button as shown in Figure 4.8.

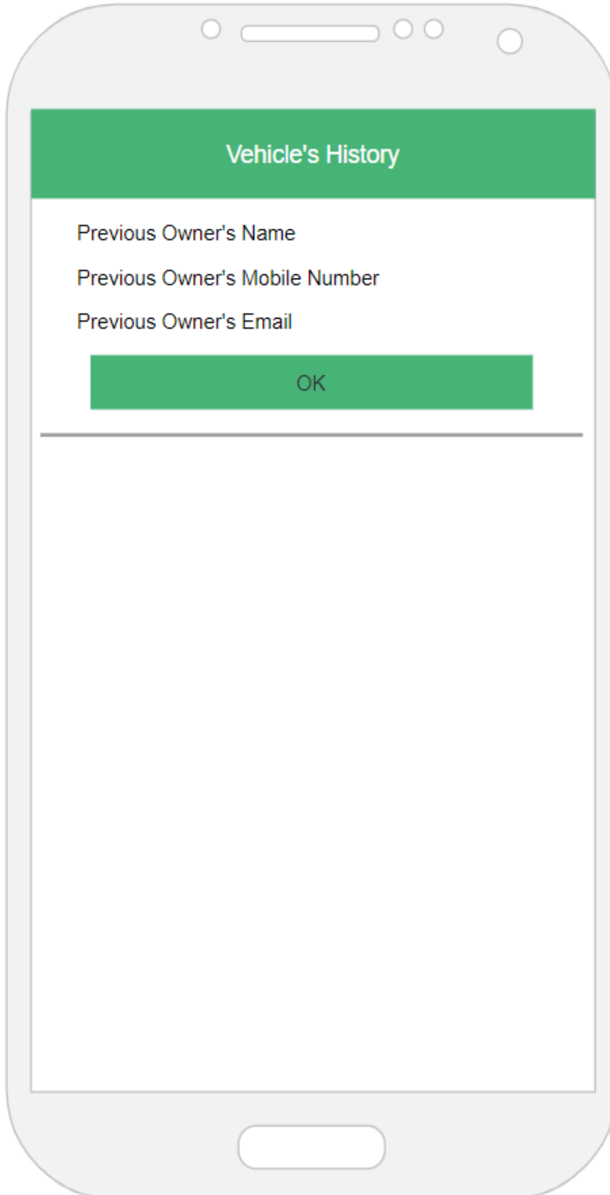

Figure 4.8: Vehicles History Screen

4.5.2 Web Application Wireframes

This screen shows how the Authority, Owner and Agent can trace the history of the vehicle back to the original owner.

Login and Register

Users of the system logged and registered into the system through the log in and registration pages as shown in Appendix C.

Vehicle Registration

Users could be able to register their vehicles through the registration page as shown in Figure 4.9.

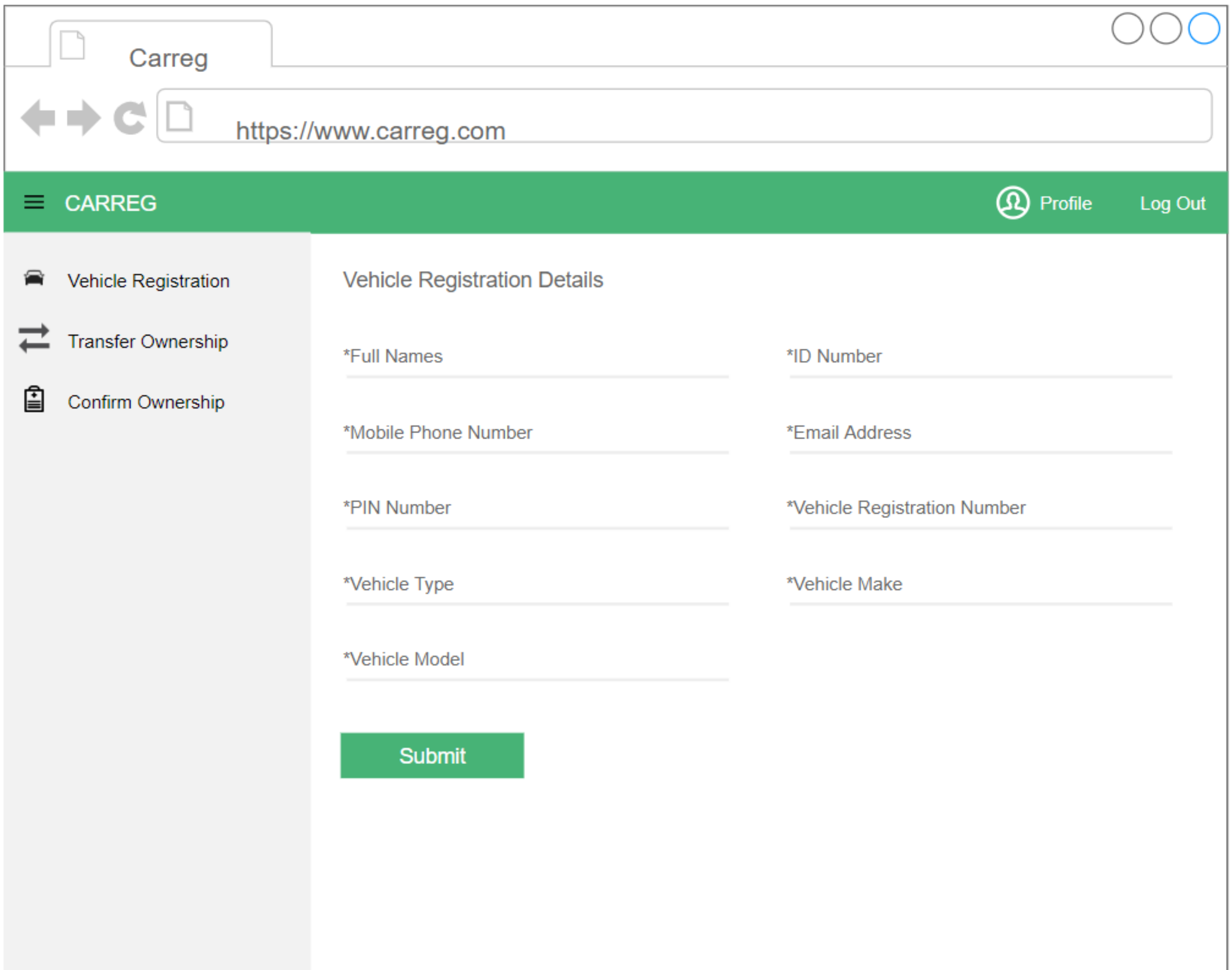

Figure 4.9: Vehicle Registration

Vehicle Transfer

A User could initiate a vehicle transfer to another user with all the details required as shown in Figure 4.10.

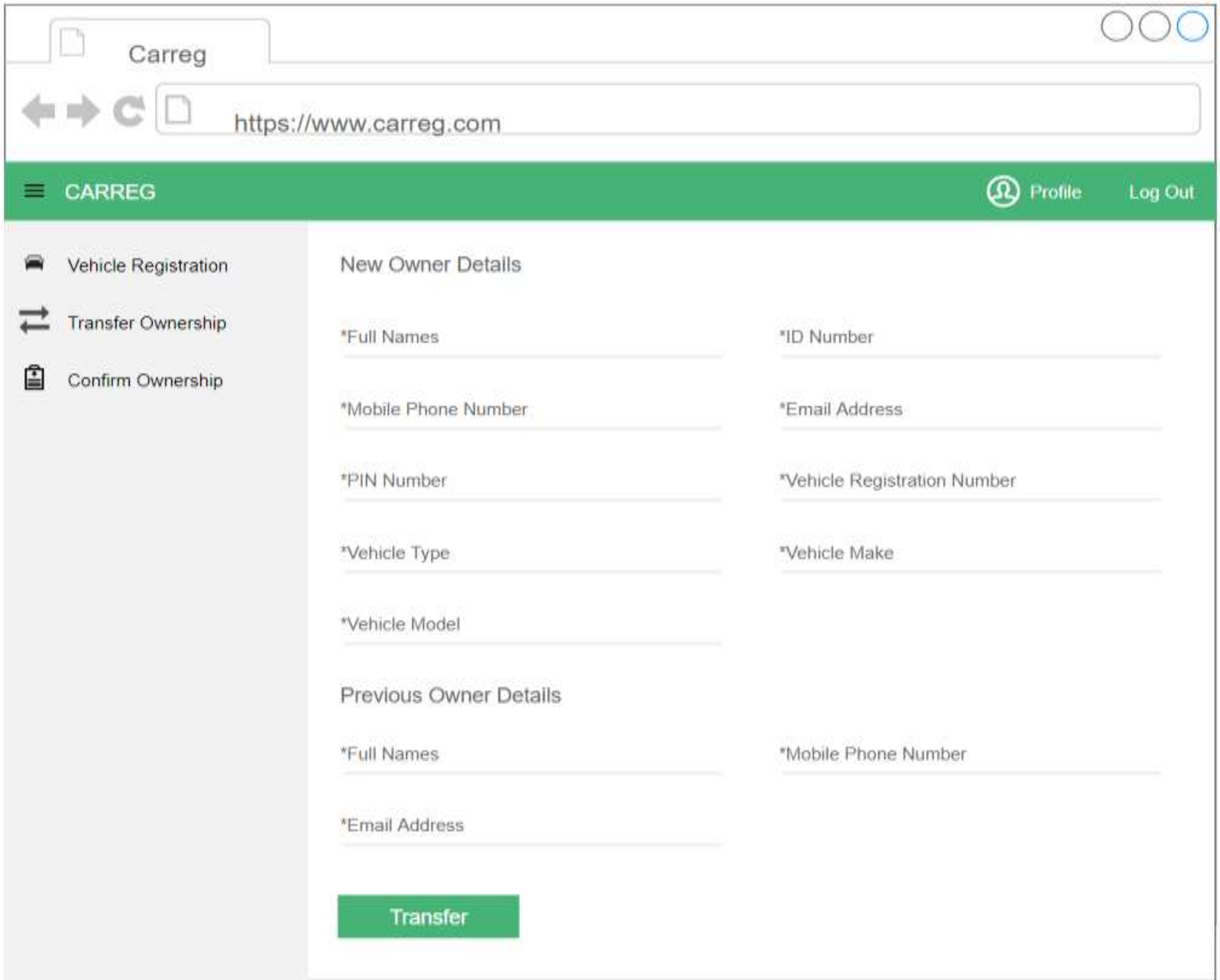

Figure 4.10: Vehicle Transfer

Confirmation of Vehicle Transfer

A User accepts a vehicle transfer by verifying the vehicle details as shown in Figure 4.11.

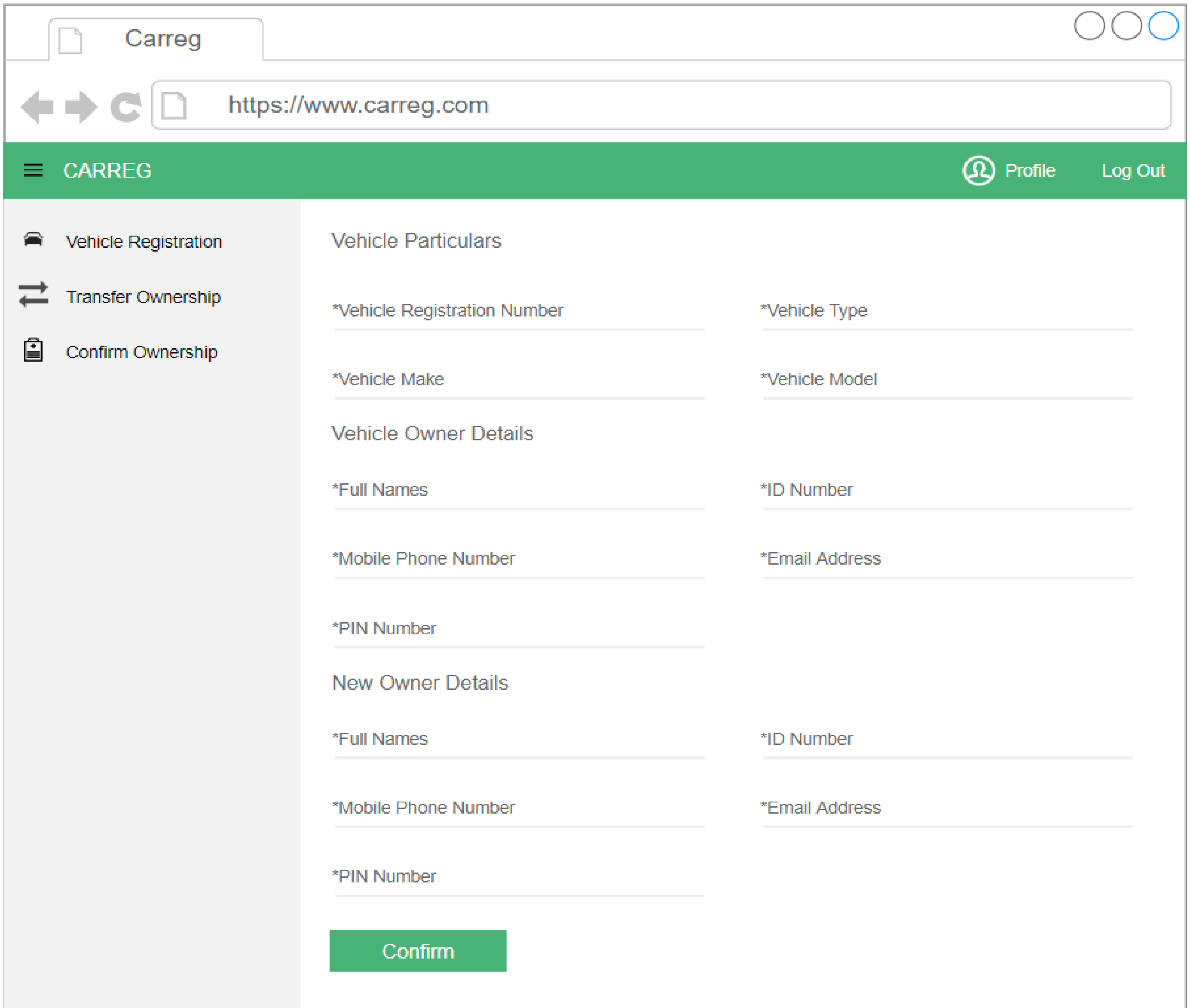

Figure 4.11: Confirmation of Vehicle Transfer

Chapter Five: System Implementation and Testing

5.1 Overview

This chapter focuses on the development of the blockchain-based vehicle registration system and explains the implementation of the system functionality and the requirements needed for the application to function. Screenshots are provided to show the different system modules and how the user interacts with the application.

5.2 Functionality of the System

The functionality of the system can be categorised into the mobile and web application functionalities.

5.2.1 Mobile Application Functionality

The mobile application enables the users to register and log into the system. Once users are logged into the system, they can view vehicles registered under them.

Furthermore, users can get to query the history of the vehicle, that is, other past vehicle owners.

5.2.2 Web Application Functionality

The web application enables users to register and log into the system. It is during submission of the vehicle registration details that this block of transaction is committed to the ledger. Other features available include, vehicle transfer where users can transfer vehicle ownership to other parties. This transaction is verified to ensure that the asset is not sent to multiple participants at the same time. Once the verification is done then the transfer can be committed to the ledger.

The same process is applied for vehicle ownership confirmation. Once a user confirms ownership of the vehicle, then the status of the previous owner indicates they transferred the vehicle and the new vehicle owner's status indicates ownership of the vehicle.

5.3 Hardware Environment

The application ran on an Android device, with Android One version quad-core processor of 1.3 Gigahertz speed, 6 Gigabytes RAM capacity and a 128 Gigabytes hard drive capacity with a 5.9-inch screen size.

Desktop computer specifications included a 16 Gigabytes RAM capacity, core i7 processor of speed 1.9 Gigahertz and a 1 Terabyte hard drive capacity.

5.4 Software Environment

The mobile application ran on an Android Operating System with the source code written in Java. The application was compiled and tested using the Software Development Kit (SDK) and an Android device. The application was compatible with the latest android version 11 down to android devices on a minimum of version 2.0. Structured Query Language (SQL) was used as the database query language for the MySQL database and JSON used as the web service language for communication between the database, the ledger and both the android and the web application front-end. Android was preferred due to its large online development community, availability and ease of use of Android Development Tools (ADT).

The web application was developed using the AngularJS framework and hosted on an online apache HTTP server. AngularJS was picked since it is open source and had a large community of online developers and is robust in implementing web applications.

The database ran on MySQL, while the ledger was developed using the Hyperledger Fabric framework which is used for implementing enterprise grade, permissioned blockchain networks with known participants.

5.5 Mobile Application Modules

Users interacted with the mobile application via the various modules developed. The major modules of the application are discussed below.

5.5.1 Login and Registration

The vehicle owner is authenticated on the login screen using his/her ID number and password. If the user has not been registered on the system, they can click on the register link to access the registration form.

The application only handles the vehicle owners. The user login and registration modules are as shown in Appendix C.

5.5.2 Main Page

Once the owner has successfully logged into the application, they are redirected to the main page which displays vehicle(s) information of the user.

These includes all the vehicles registered under the owner and their particulars as seen in Figure 5.1.

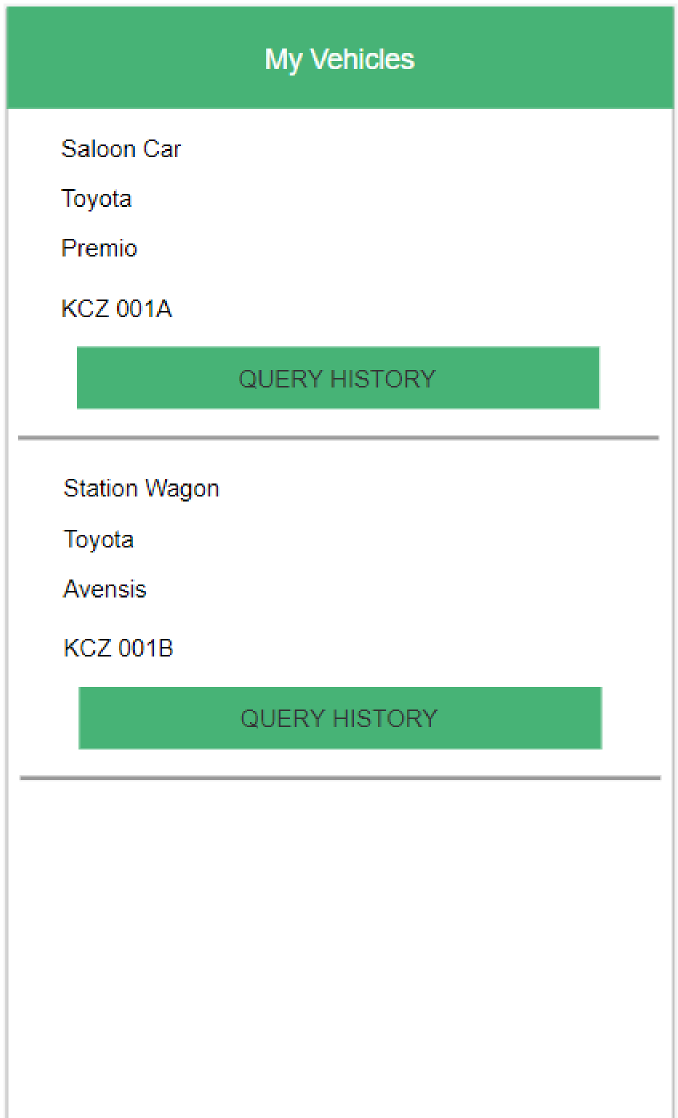

Figure 5.1: User Vehicles Display

5.5.3 Vehicle History

The main page displays all the vehicle information and under each vehicle there is a query history button which when pressed queries the history of a vehicle from the ledger.

It returns the particulars of the previous owner of the vehicle. The module is shown in Figure 5.2.

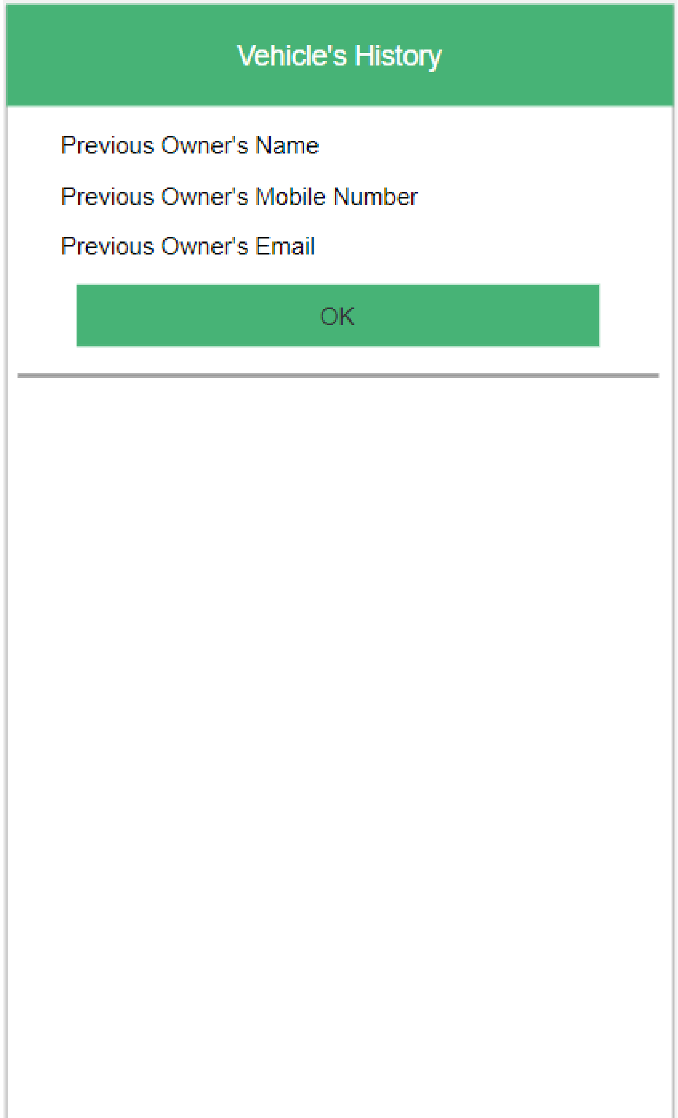

Figure 5.2: Vehicle History Display

5.6 Web Backend Modules

The web-based backend is used by the all the users, that is, the authority, owners and agents to manage the vehicles and all the transactions involved with it.

A role-based access has been implemented such that each participant has specific roles assigned to them as mentioned in Chapter 4.

5.6.1 User Authentication

Users logs into the system backend by providing their login credentials. The login page ensures that unauthorized users cannot get access to the system. There is a link for new users to register into the system as well. The log in and register modules for owners and agents are as shown in Appendix C.

5.6.2 Vehicle Registration

This feature was implemented on the web interface and allowed users to register their vehicles by submitting details with regards to the vehicle.

The vehicle registration module is shown in Figure 5.3.

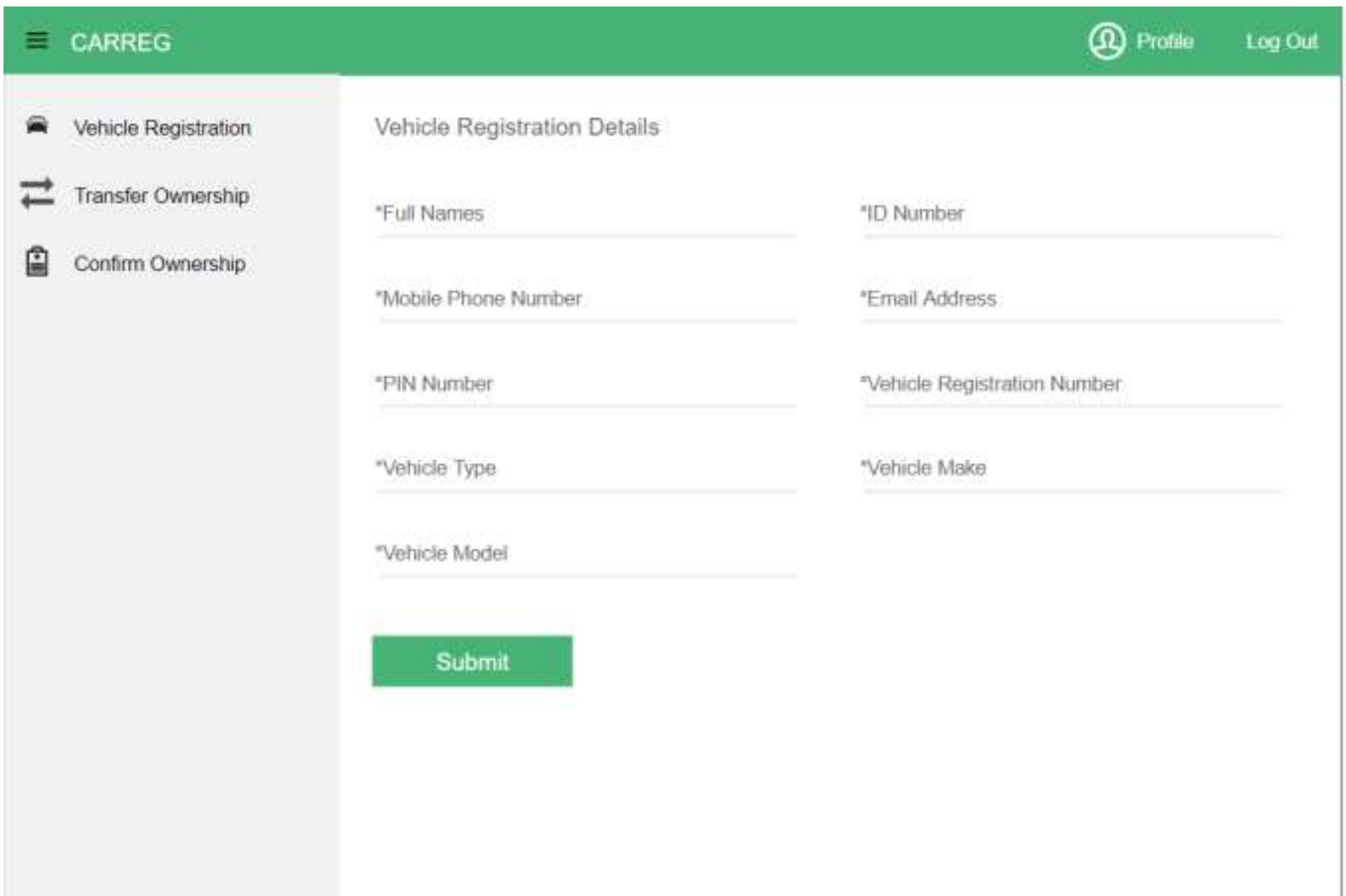

Figure 5.3: Vehicle Registration Page

5.6.3 Transfer Vehicles

Once vehicles were registered users could transfer vehicle ownership to other users by filling the transfer form shown on Figure 5.4.

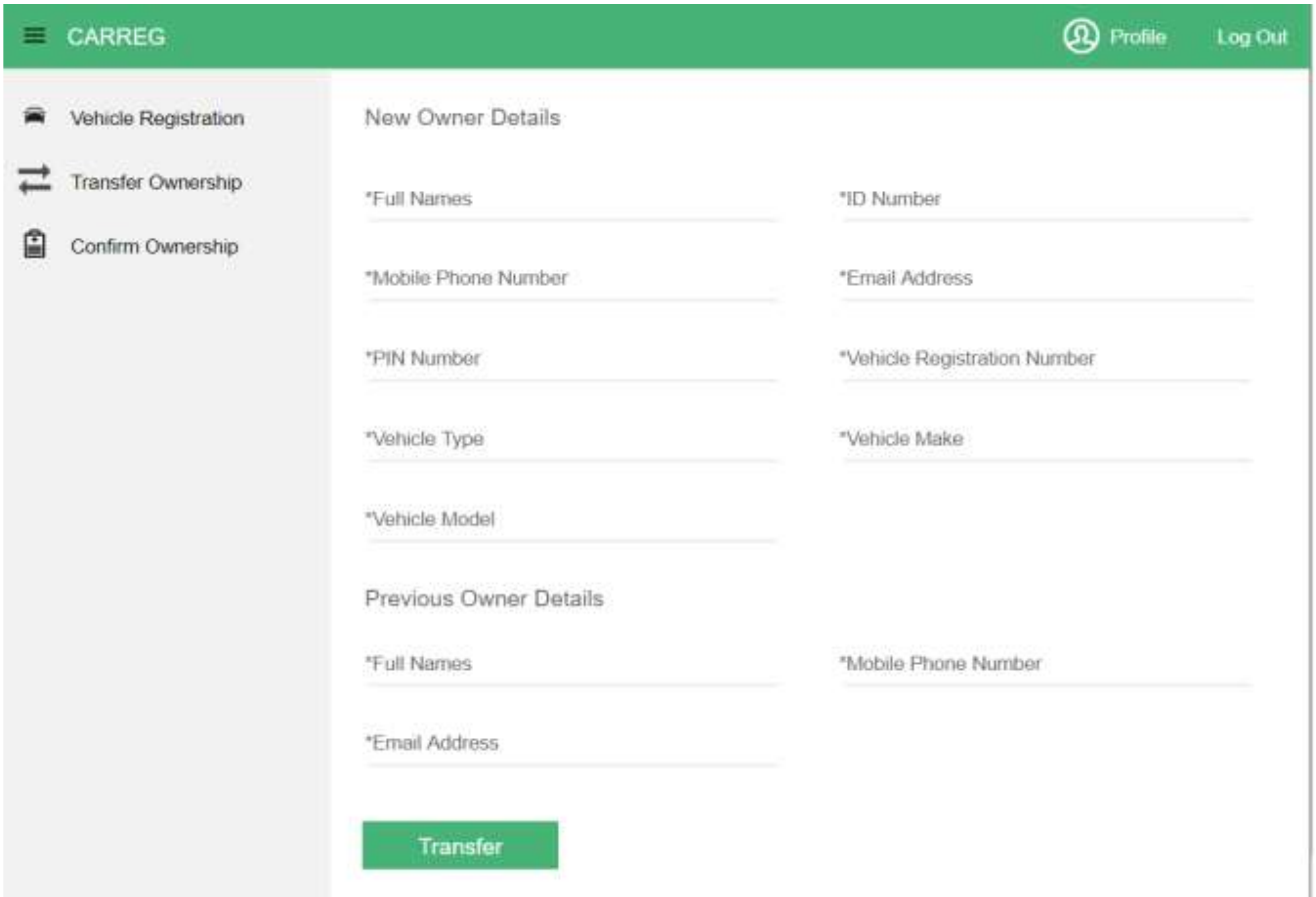

Figure 5.4: Transfer Vehicle Ownership Page

5.6.4 Confirm Vehicles

Once a vehicle has been transferred to a new owner, the new owner can view the vehicle particulars before accepting ownership.

Once the transfer has been completed this transaction is committed to the blockchain. The confirmation page is as shown in Figure 5.5.

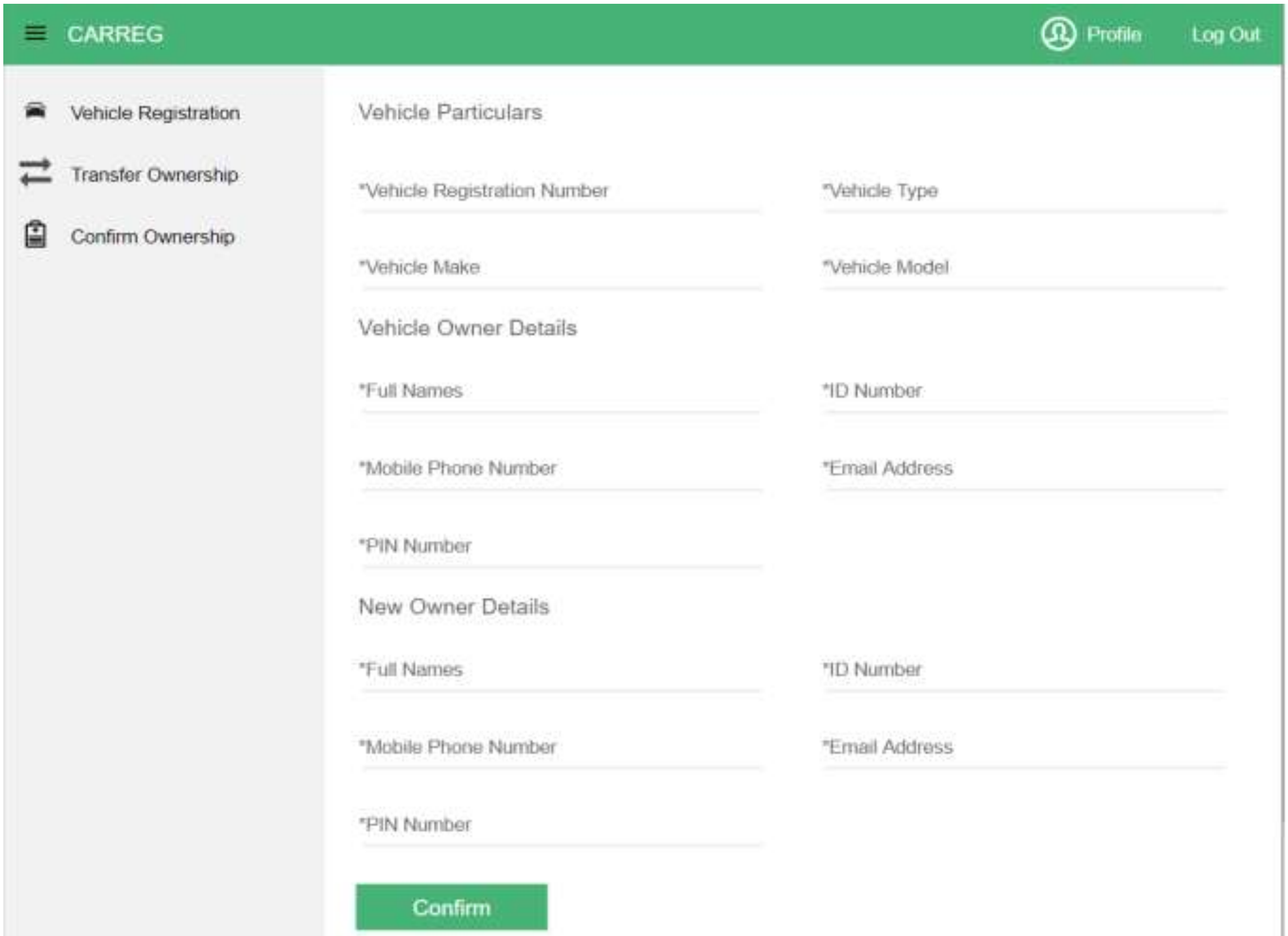

Figure 5.5: Confirm Vehicle Ownership Page

5.7 Testing

This section described tests that were performed on both the mobile and web application. Testing was done on four main areas; functionality tests, usability tests, compatibility tests and validation tests.

5.7.1 Functional Testing

Functional tests were carried to determine whether the system design and its implementation was a success or a failure. This was done by manually performing test cases on functionalities such as user account creation, login and logout, vehicle registration, vehicle transfer and confirmation of vehicle ownership transfer.

The test cases are documented below in this section. The results from the survey was shown by the Figure 5.6.

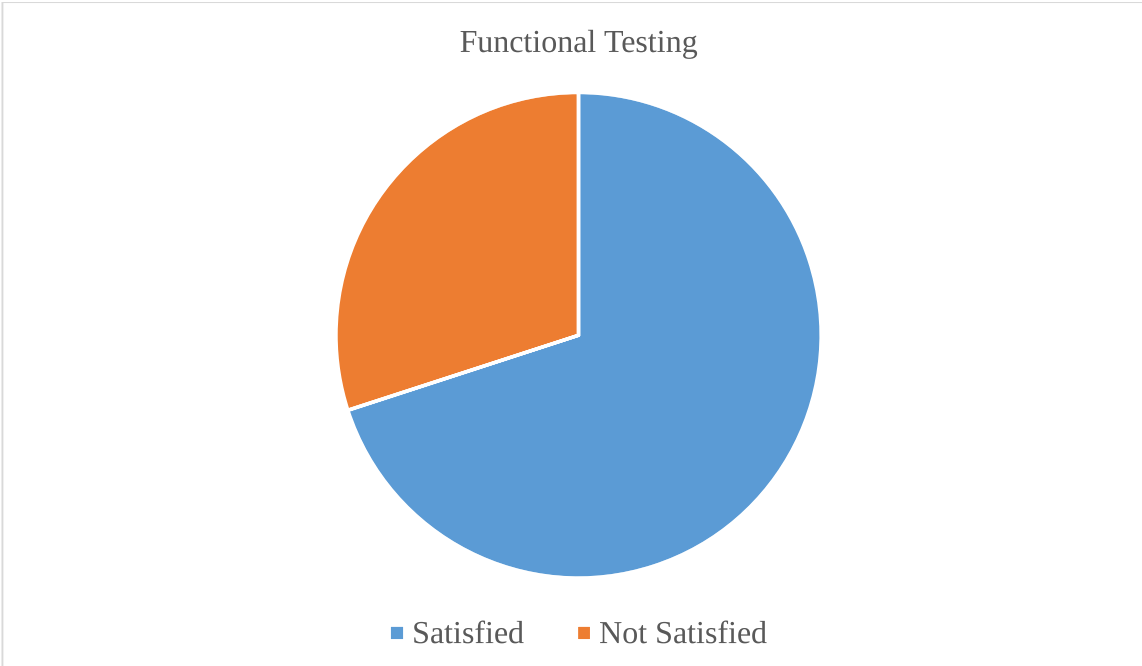

Figure 5.6: Users' Functional Testing Response

Different use cases of the system were tested with results being flagged off as a success or failure. Below are the test cases carried out and their results.

User Account Creation

Table 5.1: User Account Creation Test Case

Test Case Name: Creating User Account		**Test Case: 1**	
Brief Description: Users create their accounts by filling all the registration fields then they are required to press the submit button and upon successful submission a user account is created.			
Pre-condition: The user should have downloaded the application from the Google Play Store to be able to use the application.			
Step	**Action**	**Expected results**	**Pass/Fail**

1.	User runs the application.	The application loads the login page.	Pass
2.	User taps on the register link to create an account in the system.	The application loads the registration screen.	Pass
3	The user fills all the required registration fields and taps on the submit button.	The application returns a success message and redirects the user to the login page.	Pass
Post condition: User can now have access to the system by logging in.			

Login and Logout Test Case

Table 5.2: Login and Logout Test Case

Test Case Name: Login and Logout of the System		**Test Case: 2**	
Brief Description: Users login to the system using their ID numbers and passwords and logout once they want to exit the system.			
Pre-condition: The user should have downloaded the application from the Google Play Store to be able to use the application.			
Step	**Action**	**Expected results**	**Pass/Fail**
1.	User runs the application.	The application loads the login page.	Pass
2.	User fills in the login credentials to access the system.	The application logins in the user and the	Pass

		home screen is displayed.	
3	The user logout of the system once they are done using it.	The application redirects the user back to the login screen.	Pass
Post condition: User can now utilise the system's services.			

Add Vehicle Registration Details

Table 5.3: Vehicle Registration Test Case

Test Case Name: Add Vehicle Registration Details		**Test Case: 3**	
Brief Description: Users login to the system using their ID numbers and passwords and once logged in they can add the vehicle registration details as well as view the past vehicle history.			
Pre-condition: The user should be logged in to the system.			
Step	**Action**	**Expected results**	**Pass/Fail**
1.	User logs into the application.	The application loads the service menu.	Pass
2.	User taps on the register vehicle within the menu.	The application loads a vehicle registration form.	Pass
3	The user fills the vehicle's history particulars.	The application adds the vehicle to the user's vehicle list.	Pass

Post condition: User can save the vehicle particulars record.			

Transfer Vehicle Ownership

Table 5.4: Vehicle Transfer Test Case

Test Case Name: Transfer Vehicle Ownership		**Test Case: 4**	
Brief Description: Once a user has logged into the system and registered, they can be able to transfer vehicle ownership.			
Pre-condition: The user should be logged into the system and vehicle must be registered.			
Step	**Action**	**Expected results**	**Pass/Fail**
1.	User logs into the application.	The application loads the service menu.	Pass
2.	User taps on the transfer vehicle within the menu.	The application loads a vehicle transfer form.	Pass
3	The user keys in the transfer details.	The system submits the transfer details and issues a successful alert.	Pass
Post condition: User can perform other vehicle related transactions.			

Confirm Ownership Transfer

Table 5.5: Confirm Vehicle Ownership Transfer Test Case

Test Case Name: Confirm Ownership Transfer		**Test Case: 5**	
Brief Description: A user can accept ownership of a vehicle that has been transferred to them by another user.			
Pre-condition: The user should be logged into the system and vehicle must be transferred to them.			
Step	**Action**	**Expected results**	**Pass/Fail**
1.	User logs into the application.	The application loads the service menu.	Pass
2.	User taps on the confirm vehicle within the menu.	The application loads a vehicle confirm form.	Pass
3	The application verifies the confirm transfer details which have the details of the past vehicle owner.	The system submits the confirm vehicle transfer details and issues a successful alert.	Pass
Post condition: User can view the confirmed vehicle.			

5.7.2 Usability Testing

Usability testing was carried out to ascertain the user friendliness of the system and how a new user interacts with the system and whether they experience ease of use or not. Input from users of the system was collected through the use of a questionnaire as shown in Appendix B.

The responses were shown in the Figure 5.7.

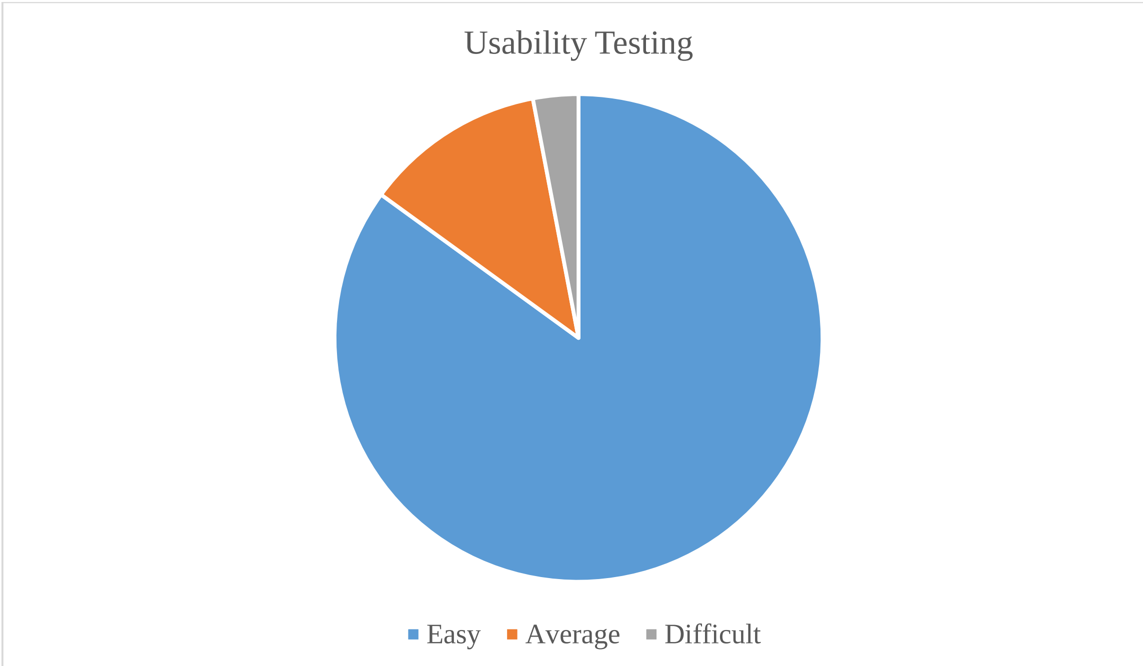

Figure 5.7: Usability Testing Response

Table 5.6 shows the usability tests performed.

Table 5.6: Usability Test Case

Test Case Name: Usability of the Application.			
Test Description: Test for Usability Application.			
Pre-Condition: Application launch must have been successful.			
Post- Condition: Ease of use of the application by the system.			
Step	Actions	Expected Response	Result
a)	Users can access the menu items and interact with them seamlessly.	Menu items should be visible, clickable and functional.	Pass

b)	Users can navigate the application with ease.	An appealing user interface with all the components well in place.	Pass

5.7.3 Compatibility Testing

This testing was done to ensure that both the mobile and web application were compatible with the existing platforms. The mobile application was tested against the existing Android versions while the web application was tested against the most commonly used web browsers.

Android Platform Testing

Compatibility test conducted for each of the available Android platforms is shown in Table 5.7.

Table 5.7: Android Compatibility Test Case

Android Version Number(s)	Compatible
Android 1.0	Yes
Android 1.1	Yes
Android 1.6	Yes
Android 2.0-2.1	Yes
Android 2.2-2.2.3	Yes
Android 2.3-2.3.7	Yes
Android 3.0-3.26	Yes
Android 4.0-4.0.4	Yes
Android 4.1-4.3.1	Yes
Android 4.4-4.4.4	Yes
Android 5.0-5.1.1	Yes

Android 6.0-6.0.1	Yes
Android 7.0-7.1.2	Yes
Android 8.0-8.1	Yes
Android 9.0	Yes
Android 10.0	Yes

Web Browser Testing

Compatibility test conducted for the various web browsers is shown in Table 5.8.

Table 5.8: Web Browser Compatibility Test Case

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

5.7.4 Validation

The system was validated through the use of a test case in Table 5.9 alongside a questionnaire that was issued to users as shown in Appendix B.

The responses were documented as shown in Figure 5.8.

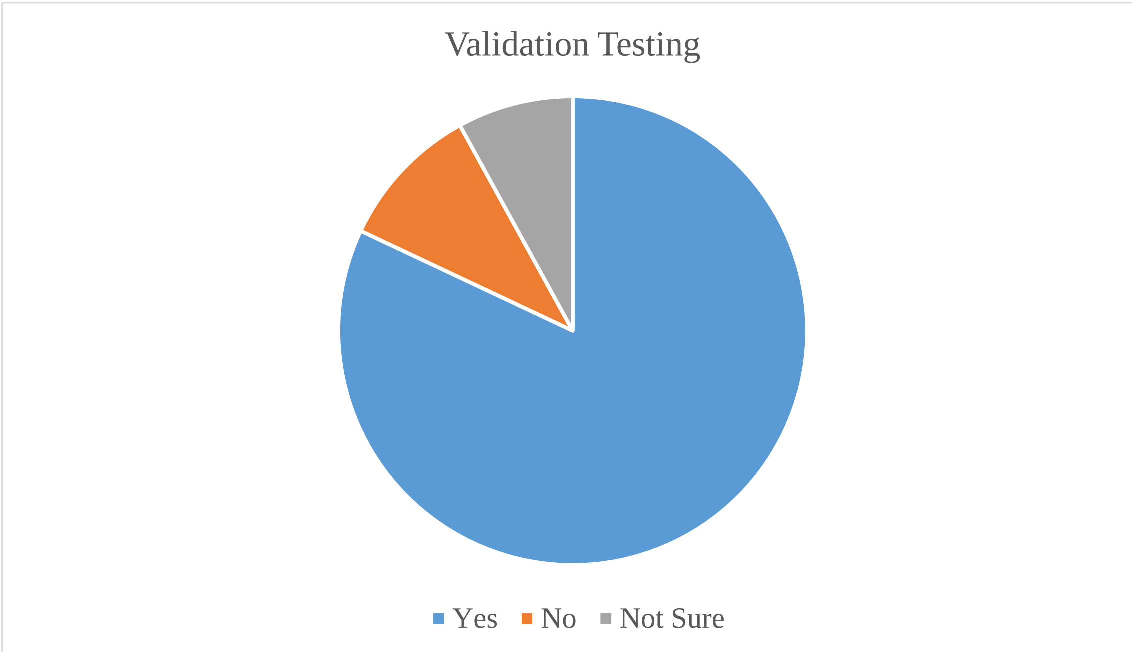

Figure 5.8: Validation Testing Response

Table 5.9: Validation Test Case

Test Case Name: Validation of the Application Test Description: Test for Validation of the Application			
Step	Action	Expected Response	Result
a)	System Accuracy and Speed	User's input is checked to ensure it is of the correct format and that the information is uploaded to the database in less than 30 seconds.	Pass

Chapter Six: Discussions of Key Findings

6.1 Overview

The purpose of this research was to identify challenges faced in keeping track of vehicle registration and vehicle ownership transfer transactions, to review the existing vehicle registration models and the challenges they faced. Furthermore, the research designed, developed and tested a blockchain-based solution for vehicle registration and finally validated the blockchain-based prototype.

The aim was to identify a suitable technique that would be adopted to solve the challenges of tracking vehicle transfer and ownership transactions as well as the challenges faced by the existing vehicle registration models. The findings of the research helped identify that a blockchain-based application was the suitable technique and a prototype was developed. The prototype was both a mobile and web application.

The mobile application was developed to capture registration details of new users into the system. A user can as well view all vehicles registered under them and the history of the particular vehicles. The web application would also be able to capture users' registration details but extend other services such as vehicle registration, vehicle transfer and vehicle ownership confirmation.

6.2 Discussion in Relation to Research Objectives

The first objective was achieved by reviewing existing vehicle registration models in the literature review covered in Chapter Two. In the case of Tejas, et al., (2017) the system they developed lacked mechanism to keep track of all vehicle owner(s). According to James, Ansa and Udoeka (2016) the system they developed only enabled registration of vehicles but has no feature for transfer of vehicle ownership. This study therefore came up with a system that enabled registration of vehicles, transfer of vehicle ownership as well as confirmation of ownership transfer. A feature for viewing past vehicle owners was also added enabling new owners to view the vehicle history.

The second objective was addressed by reviewing related works in the literature review covered in Chapter Two. The first system reviewed did not have the mechanism to identify owner(s) of a particular vehicle. This meant that a new vehicle owner was not able to know how many people if any had owned the vehicle before. The second system was limited to only vehicle registrations. It lacked features that could enable vehicle transfers and confirmation of ownership transfer. The third system was unable to record all the transactions related to the vehicle registration and transfer transactions. In case a fraudulent transaction happened, the system was unable to keep track of the same. This study developed a blockchain-based solution with the ability to register vehicles, transfer vehicles as well as confirm ownership transfer. Each transaction that took place relating to the vehicle was stored in a ledger for purposes of keeping track of the information.

The third objective was achieved through the development of the product which is both a mobile and web application. This was shown by the mockups of the system, the database schemas and the entity relationship diagrams as shown in chapter four. To be able to keep track of all transactions as opposed to the reviewed systems, blockchain technology was used. Each block of transaction was verified before being committed to the ledger. The blockchain technology was implemented using the Hyperledger Fabric framework.

Validating the effectiveness of the solution which was the fourth objective was done by users interacting with the system through registering of vehicles, transferring the vehicles as well as confirming ownership transfer. Users' level of satisfaction after interacting with the system and comparing it to the existing ones indicated that the application managed to solve the problem.

Chapter Seven: Conclusions, Recommendations and Future Work

7.1 Conclusions

Vehicle ownership identification had been a key challenge for long because of the significant variance in the vehicle registration details issued by Motor Vehicle Administrations. Existing systems lacked the mechanism of keeping track of vehicle registration transactions. Relevant stakeholders had challenges in determining legitimate vehicle owners. This was the case when it came to vehicle transfers since new vehicle owners were unable to get details of previous vehicle owner(s).

The research findings therefore led to the development of a blockchain-based car registration prototype which was both a mobile and web application. The system would capture vehicle registration details, facilitate vehicle transfer as well as confirmation of vehicle transfer.

A blockchain-based solution is a critical component of the research findings due to its immutability nature. This ensured that every block of transaction had to be verified before being committed to the immutable ledger. A trail of all vehicle owner(s) could therefore be retrieved from the system during confirmation of vehicle ownership transfers by querying the ledger.

7.2 Recommendations

Determining legitimate vehicle owners through blockchain technology was not only critical for the relevant stakeholders but also formed the basis for future research on how to incorporate blockchain in the transport related systems. It was therefore a platform that could ensure provision of research grants from the government or international agencies.

Therefore, I recommended that the management of NTSA and the ministry of transport should consider adopting blockchain technology in their various systems such as the ones for tracking speed limits and detection of drunk drivers. This can help in determining drivers' score within a period of time and enforcing relevant disciplinary actions to rogue drivers which in turn will bring sanity to our roads by reducing traffic related offences.

7.3 Future Work

The research findings of this study were not final and there is room for improvement. This is possible due to the technological advancements taking place constantly which can be incorporated in this research. The following therefore are the areas that can be explored for future improvement of the research:

Development of all the features into the mobile application. The only feature available is registration of vehicle owners and viewing of the vehicle(s) registered under them. Features to be added include vehicle transfers and confirmation of vehicle ownership transfers as well as enabling the Authority and Agents to be enable to use the mobile application

Expanding the system to be able to cover services such as logbook application, reflective number plate application, vehicle inspection as well as online car search. This will ensure that most if not all services with regards to vehicle transactions are automated using blockchain.

The need to work in collaboration with NTSA so that the system can be able to authenticate vehicle car plates, whether or not the vehicle number plates do exist. NTSA in conjunction with KRA are responsible for issuing of car plate numbers.

The use of chat bots to be incorporated in the system that will allow users to ask questions and get instant feedback with the absence of front-end attendants. Social media bots can be able to reach more clientele due to the large number of people in social networks.

Developing the application on the iOS platform for use by users who have devices running on this respective operating system.

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Appendices

Appendix A: Requirements Gathering Questionnaire

Please provide answers to this questionnaire that will help us gather requirements on the system to be developed.

Name…………………. …………...Occupation…………………………… Date………………

1. What is your gender?
   a) Male ☐
   b) Female ☐
2. How old are you?
   a) 18 - 24 ☐
   b) 25 - 34 ☐
   c) 35 - 50 ☐
   d) Above 50 ☐
3. Do you own a vehicle?
   a) Yes ☐
   b) No ☐
4. If yes, how many do you own?
   a) 0 – 5 ☐
   b) 5 – 10 ☐
   c) More than 10 ☐
5. Are you the one who registered the vehicle on the NTSA Portal?
   a) Yes ☐
   b) No ☐
6. If no, who did it on your behalf?
   a) NTSA Agent ☐
   b) Car Dealership Agency ☐
   c) Friend/Relative ☐
7. Could you kindly list down the information you were required to fill during the registration of the vehicle?

8. Has a vehicle(s) ever been transferred to you?

a) Yes ☐

b) No ☐

9. What information were you required to fill during the transfer of the vehicle?

10. If yes (in question 8), were you able to view the history of the vehicle before accepting ownership?

a) Yes ☐

b) No ☐

11. What information were you able to view before accepting ownership of the vehicle?

12. If the particulars of your vehicle(s) were to be changed without your consent, would this be a cause for concern to you?

a) Yes ☐

b) No ☐

Appendix B: Application Validation Questionnaire

Please provide answers to this questionnaire that will help us get more insights on your opinion about the developed system.

Name…………………. …………...Occupation…………………………… Date………………

1. Did you find the application relevant?
   a) Male ☐
   b) Female ☐
2. Were you able to effectively register a vehicle?
   a) Yes ☐
   b) No ☐
3. If no, please give a reason.

   ___

   ___
4. Were you able to transfer a vehicle?
   a) Yes ☐
   b) No ☐
5. If no, please give a reason.

   ___

   ___
6. Were you able to view the vehicle history before accepting transfer ownership?
   a) Yes ☐
   b) No ☐
7. If no, please give a reason.

   ___

   ___
8. Please rate the functionality of the system (1: Excellent, 2: Very Good, 3: Good, 4: Fair, 5: Poor).
   a) 1 ☐
   b) 2 ☐

c) 3 ☐
d) 4 ☐
e) 5 ☐

9. Was the system easy to navigate?
   a) Yes ☐
   b) No ☐

10. If no, please state the challenge you experienced in navigating the system.

____

____

11. Please rate the system's user interface (1: Excellent, 2: Very Good, 3: Good, 4: Fair, 5: Poor).
    a) 1 ☐
    b) 2 ☐
    c) 3 ☐
    d) 4 ☐
    e) 5 ☐

12. Please rate the system in terms of speed and accuracy.
    a) Good ☐
    b) Average ☐
    c) Poor ☐

13. Does the system solve the problem of vehicle registration, transfer and confirmation of ownership transfer?
    a) Yes ☐
    b) No ☐

14. If no, please explain what is lacking in the system.

____

____

15. What other feature(s) in your opinion was lacking and you would like to have it incorporated in the system?

____

____

____

Appendix C: Screenshots

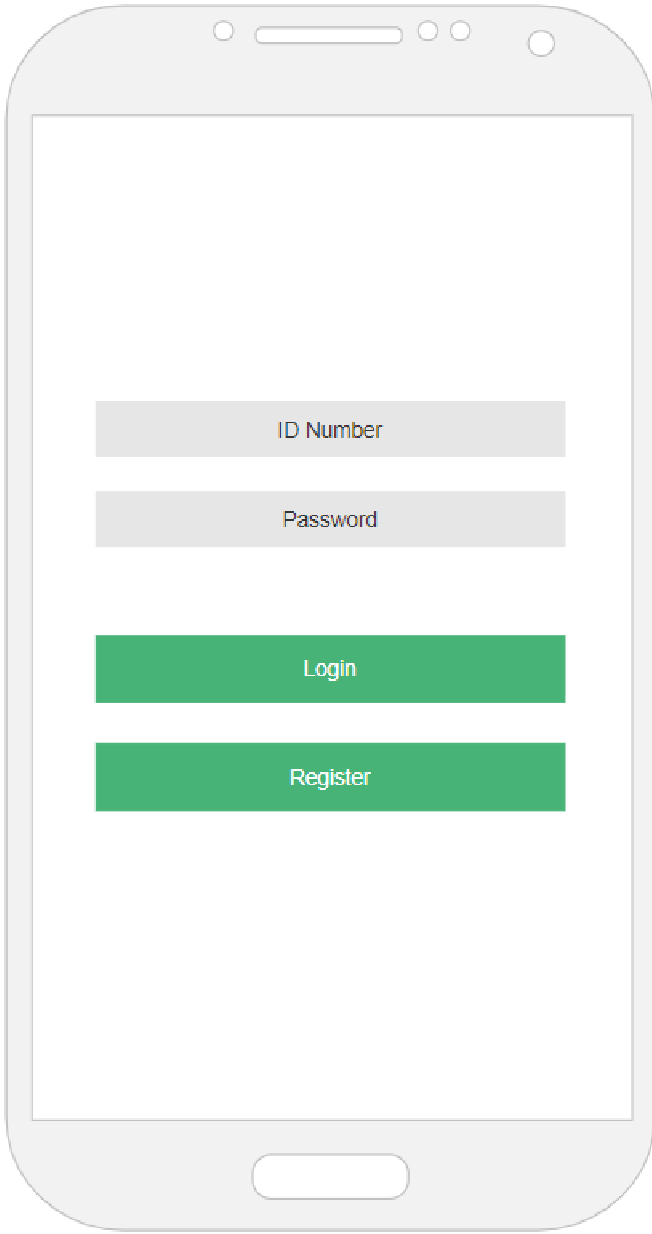

Figure C.1: Mobile Login Wireframe

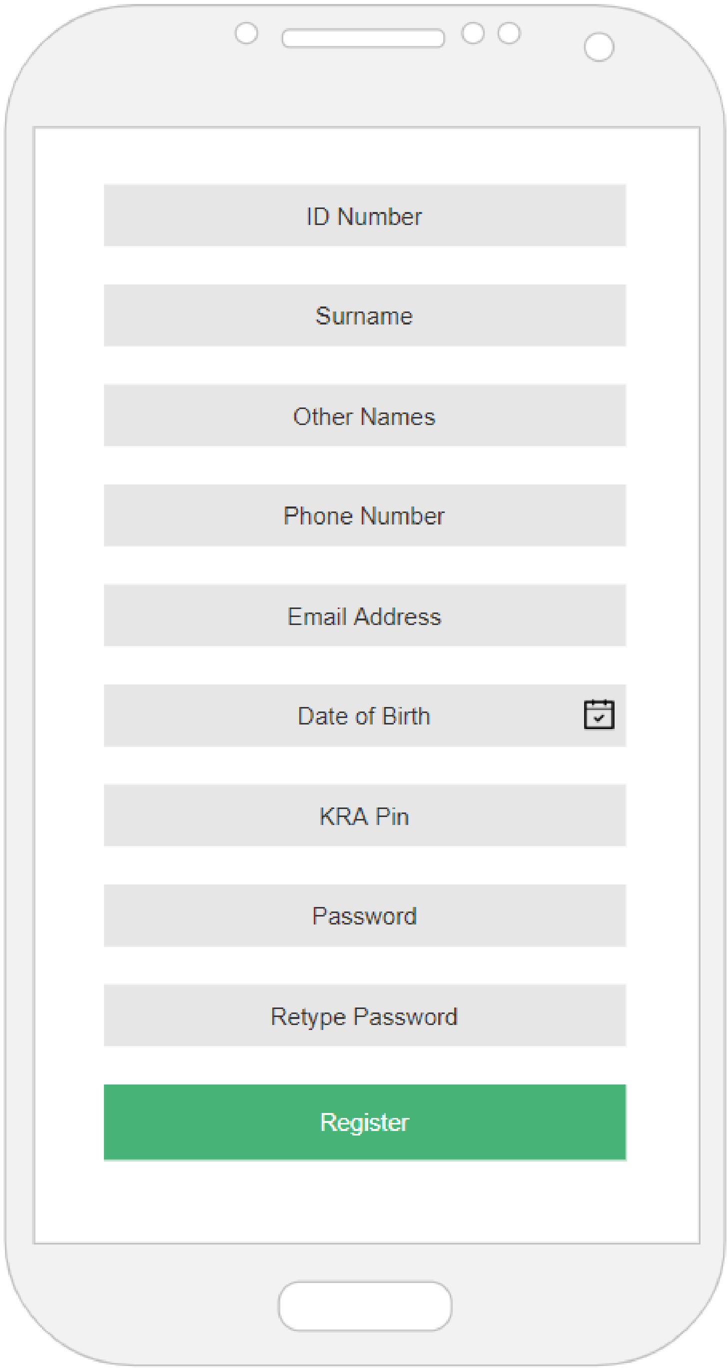

Figure C.2: Mobile Register Wireframe

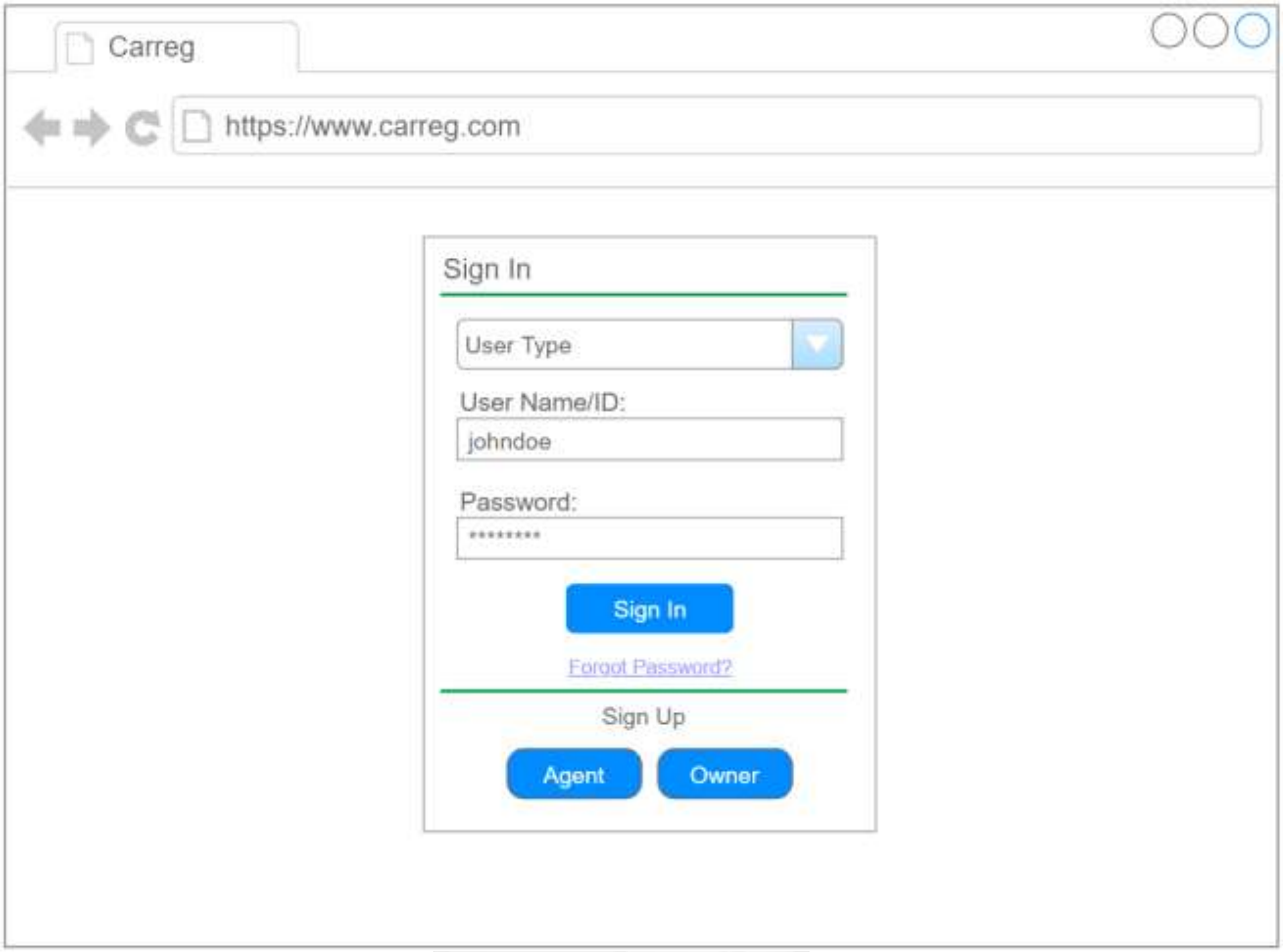

Figure C.3: Web Login Wireframe

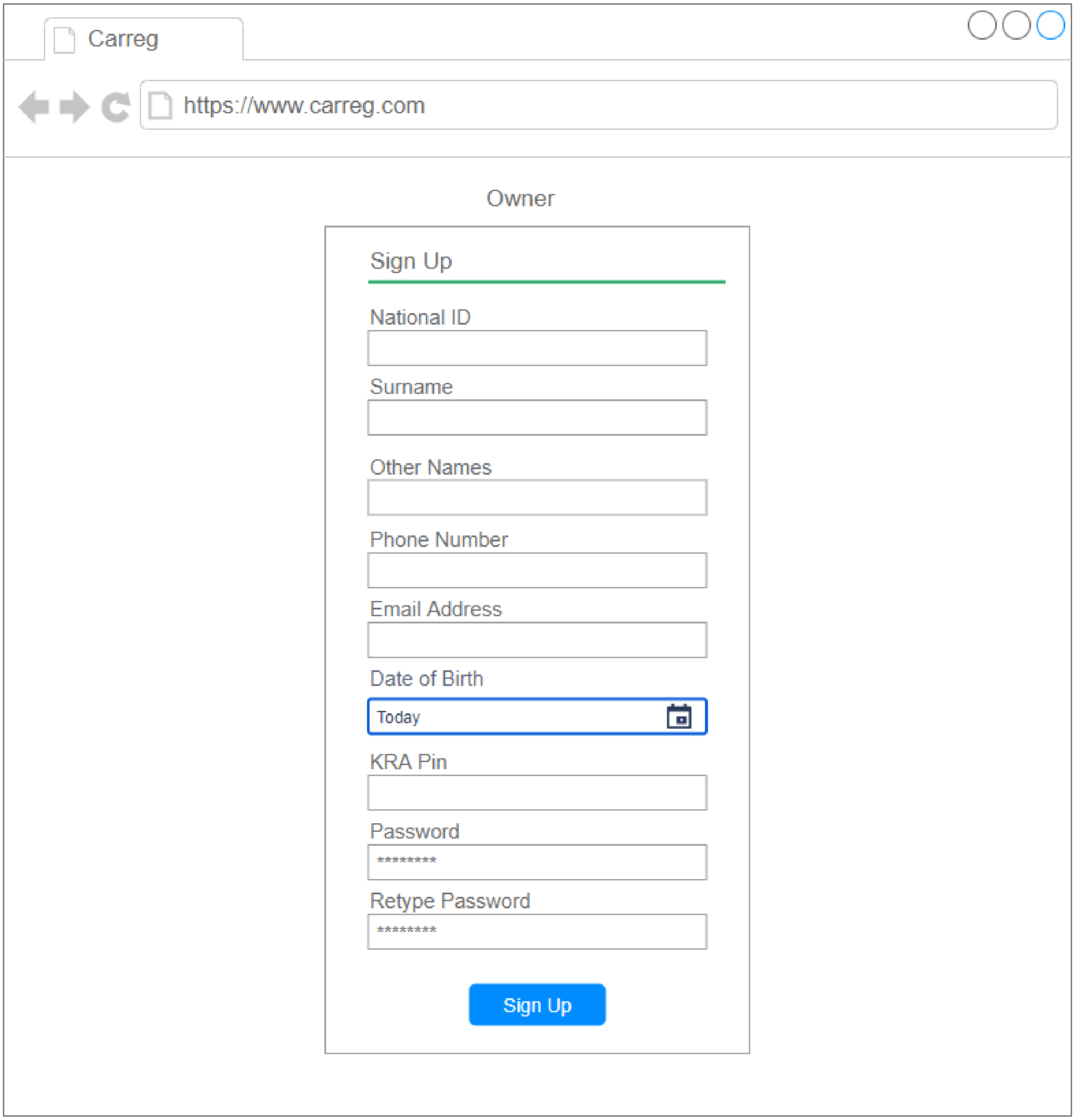

Figure C.4: Web Owner Registration Wireframe

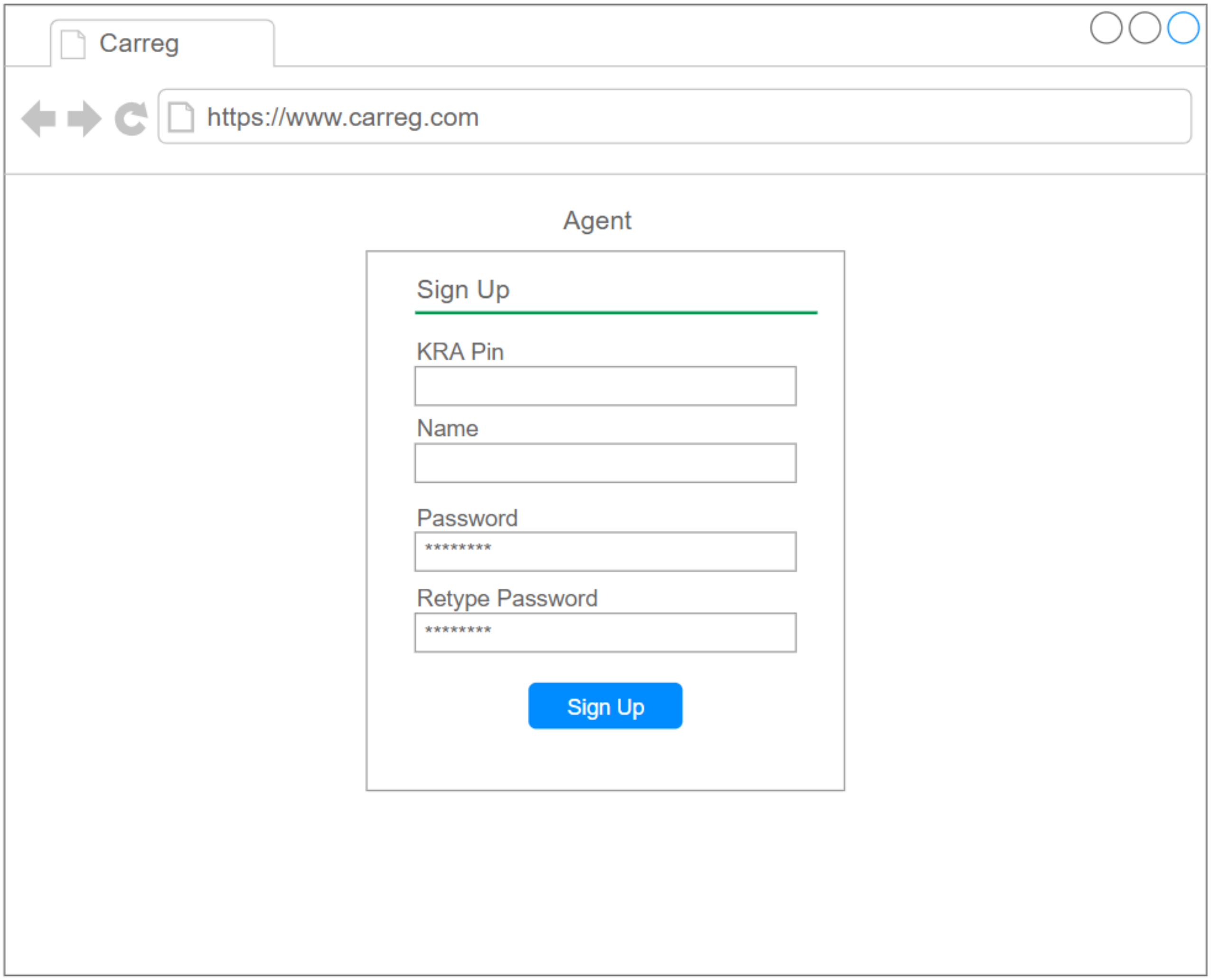

Figure C.5: Web Agent Registration Wireframe

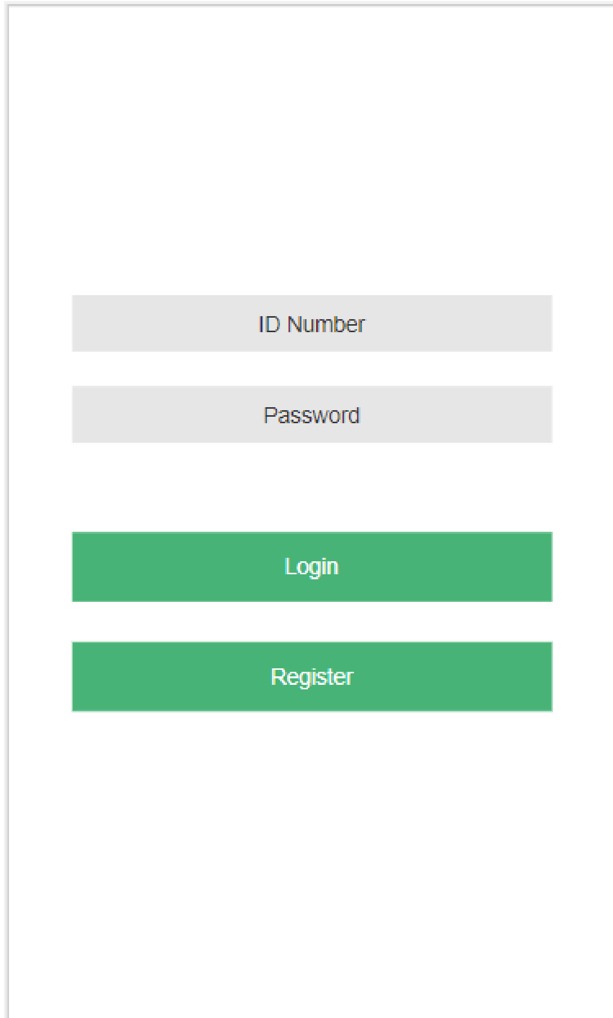

Figure C.6: Mobile Login Screen

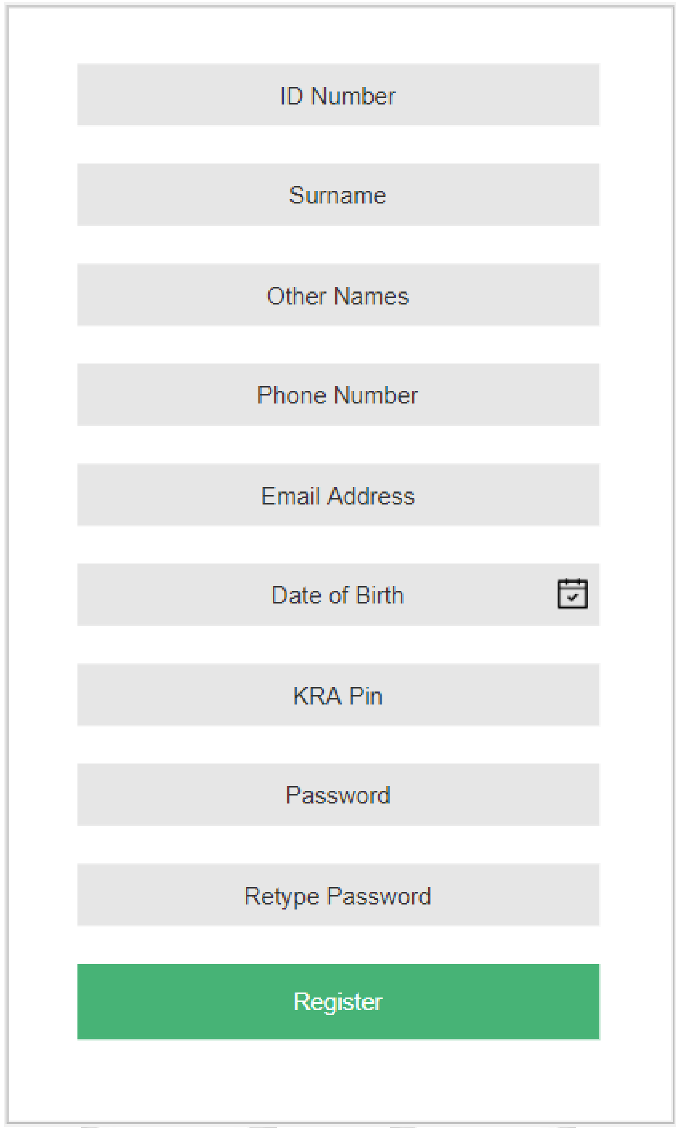

Figure C.7: Mobile Register Screen

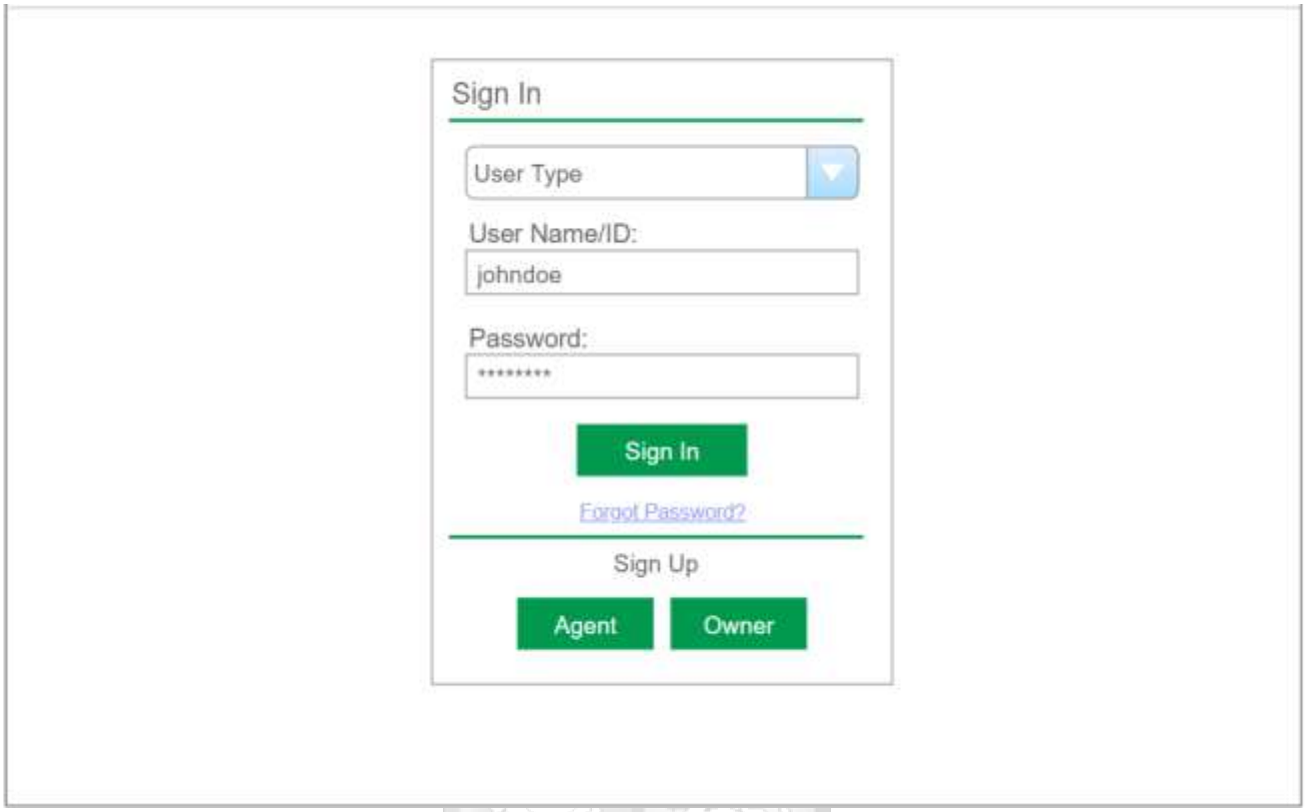

Figure C.8: Web Login Page

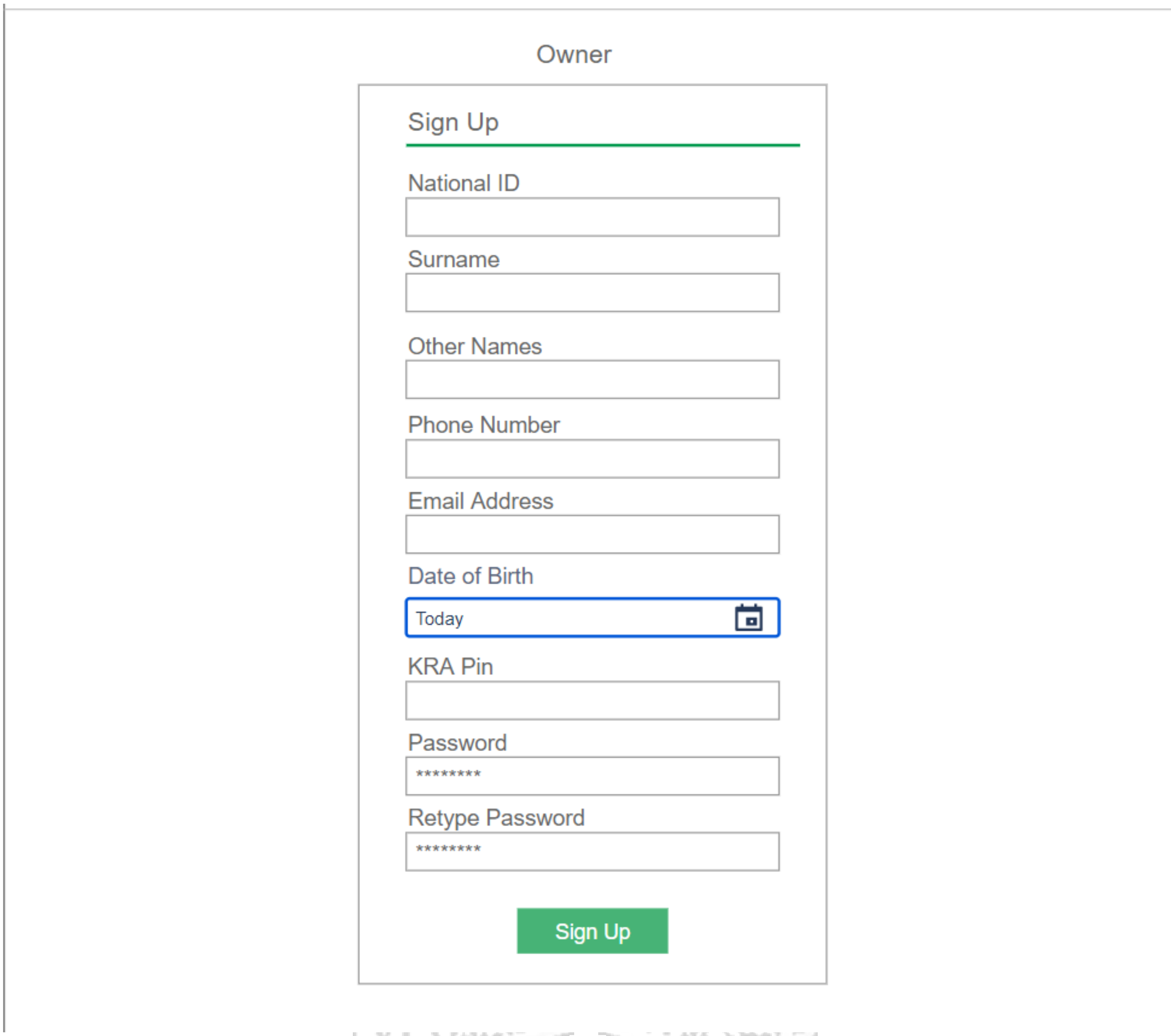

Figure C.9: Web Owner Registration Page

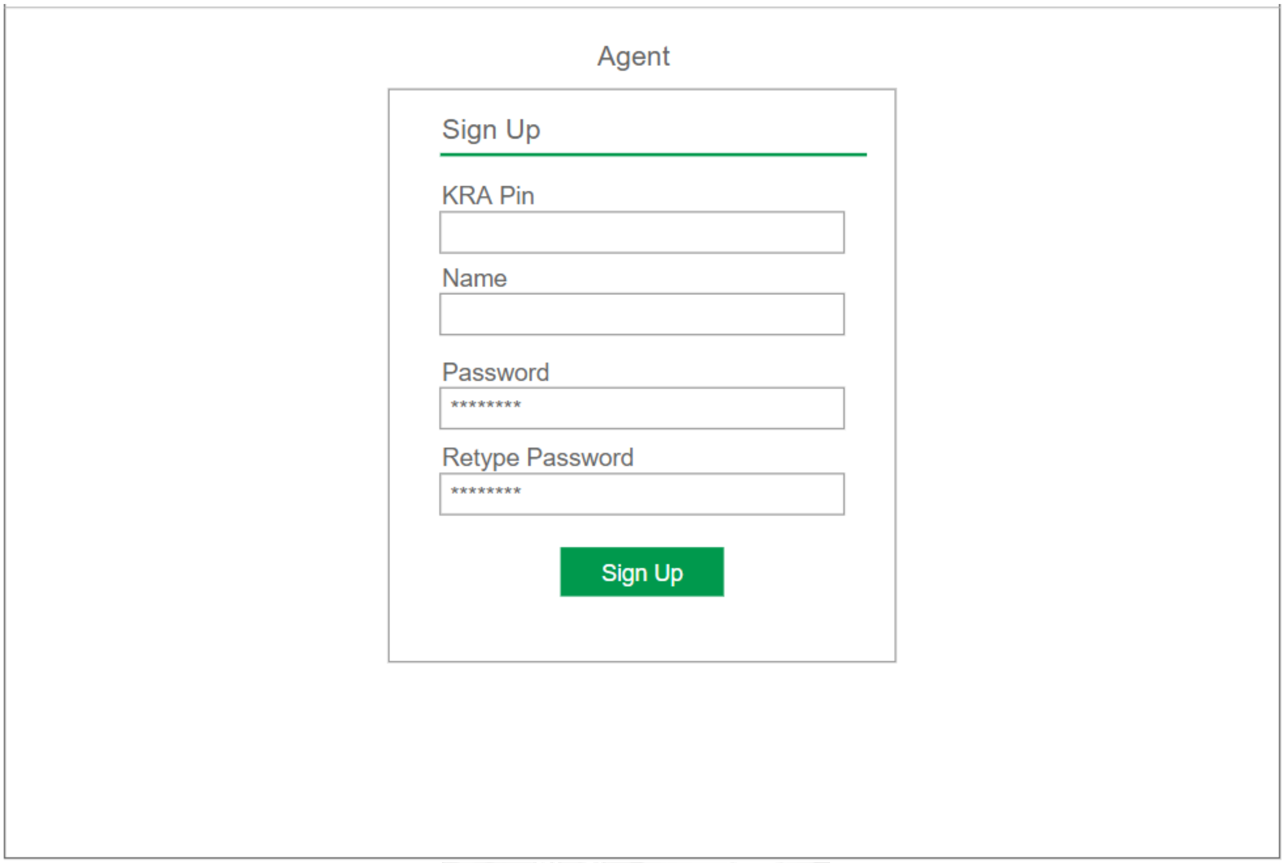

Figure C.10: Web Agent Registration Page

Appendix D: Turnitin Report