IMPLEMENTING A REMOTE SENSOR NETWORK AND AUTOMATION OF THE BUSINESS PROCESSES FOR THE FOOD RESERVE AGENCY IN ZAMBIA

BY

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DECLERATION

I, the undersigned, declare that this has not previously been submitted in candidature for any degree. The dissertation is the result of my own work and investigations, except where otherwise stated. Other sources are acknowledged by given explicit references. A complete list of references is appended.

Signature: ……………………………………………….

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ABSTRACT

Zambia's Food Reserve Agency was established by the Food Reserve Act of 1995. This act has since been updated in 2005 in order to incorporate the agency as a parastatal with the mandate to establish a national strategic food reserve. The agency is tasked with ensuring food security by being a market facilitator, encouraging efficient agricultural production and marketing systems while also providing a ready market for small scale farmers.

The current operations and management of the warehousing systems and general activities is manual and this presents several issues that can be addressed using information and communications technologies. Primary among the problems faced by the Food Reserve Agency is spoilage of grain due to unmonitored environmental conditions and theft of grain due to poor controls. In this study, using a mixed methods research strategy, qualitative and quantitative analysis, the automation of activities related to the Food Reserve Agency is proposed in an effort to make the programme more efficient and eliminate unnecessary and costly manual methods. It is shown that the introduction of technology and the use of modern warehousing in grain marketing leads to efficiencies and is also part of the United Nations 2030 Sustainable Development Goals on agriculture.

As this work primarily focused on the use of wireless sensor networks in grain marketing, related technology that can be used for remote management and monitoring of storage warehouses at which stock is kept is proposed. The Internet of Things is used as the basis for the platform of the remote sensor network and the entire implementation relies on cloud computing, the processing of big data and a very recent operating system called Android Things is used for the remote devices. Further efficiencies such as the possible use of Zambia's National Data Centre and Blockchain technology are considered for future work. In the results, a developed database for the agency is presented and this is extracted from the business rules and documents obtained in the baseline study. Further, a remote sensor network prototype is developed in order to address some of the challenges faced by the agency. A detailed discussion of the results is presented and a conclusion and recommendation section looks at the future and aligns the importance of this work to the United Nations 2030 sustainable development goals.

Keywords: Big data, sensor network, Internet of Things, Android Things

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I would like to acknowledge the work of Cynthia Muyunda which provided a very good starting point for this research. Her research into Zambia's Food Reserve Agency's business processes and suggested use of RFID technology provided a wealth of information that has been built upon and expanded to look into the use of ICT's in grain marketing in general. I would also like to acknowledge the contribution of Dr Paul Kogeda and Tshwane University in South Africa for the exchange opportunities that exposed me to the work being done with ICT's in Agriculture in South Africa. I also thank The National Science and Technology Council of Zambia for the financial aid and sponsorship of this project, The Food Reserve Agency for allowing access to their facilities, documents and staff, The Farmer Input Support Program for allowing access to their documentation and project data and finally to Dr Jackson Phiri for according me the opportunity to work on this research and complete my tertiary studies.

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CHAPTER ONE
INTRODUCTION

1.1. Introduction

Since its establishment, Zambia's Food Reserve Agency has been a key institution in ensuring food security for the republic. In times of severe drought, even neighbouring countries such as South Africa and Zimbabwe have procured their maize requirements from the Food Reserve Agency. Grain marketing is a key activity of the Food Reserve Agency. The major function of the agency is in ensuring that the nation at large has enough food stored up for the future, the term "future" is however not defined due to issues that will be discussed later on such as the unavailability of adequate and real time data. The Food Reserve Agency has also been key in ensuring that the commodity price for especially maize is regulated so as not to burden the citizens of Zambia with overwhelming costs(Nicole M. Mason & Robert J. Myers 2013). Another important function of the organization is to complement the gran marketing business already carried out by the private sector. This key organization has been managed by the same processes and procedures since its inception by an act of the Zambian parliament in 1996. The current mode of operation of the agency provides challenges that are highlighted in the problem statement of this work.

Organizations such as the Food Reserve Agency are not unique to Zambia. For example, the term strategic grain reserve is used in most countries to refer to the activities that are carried out by Zambia's Food Reserve Agency. In a more advanced economy such as the United States, initiatives such as the Farmer-Owned Grain Reserve were carried out more than 20 years ago in order to address future grain needs for that country. These grain marketing initiatives are a natural progression towards a more liberalised and private grain management system. However, in order to improve the operations of Zambia's Food Reserve Agency, ICT's will need to play a critical role in areas that have been identified as being potential benefactors of this proposal.

1.2. Introduction to the Research Study

From the advent of computers and computing systems, the goal has always been to make manual processes more efficient by being able to electronically and in some cases automatically capture, store and manipulate data. Organized data is information and information is a prerequisite to the progress of a modern society. In an age where even big data(Hakan Özkösea, Emin Sertaç Arıa & Cevriye Gencerb 2015) that was thought to have been useless until computers became powerful enough and had sufficient storage options to process and extract useful information out of it, a society seeking progress cannot afford to relegate any form of data produced by its activities to a status of worthlessness. Zambia's FRA generates a lot of data and information regarding strategic food reserves that is key for national planning. However, the organization has been facing a lot of challenges in managing this information due to a lack of automation. In 2013, the Department of Computer Science at the University of Zambia started collaborating with FRA in an effort to resolve some of the key problems through computerization of some key business processes. The outcome of this collaboration is the current research jointly funded by the National Research Foundation (NRF) of South Africa and National Science and Technological Council (NSTC) in Zambia that will be used to automate the key business processes of FRA in order to improve on its operations. The study is jointly being carried by University of Zambia in collaboration with Tshwane University of Technology in South Africa.

This paper proposes to modernize the management of the activities related to the Food Reserve Agency warehouses which include both the central and remote or satellite warehouses. In order to take full advantage of the remote sensor network, additional work has been done such as the introduction of RFID or barcode technology which is not the scope of this work but has already been undertaken by Cynthia Muyunda and Jackson Phiri in their work on radio frequency identification as applies to grain tracking(Muyunda 2016) and it is assumed here that either RFID(Chunling Sun 2012) or barcodes are already used for the purpose of tracking grain following their proposal, what we propose here is how that RFID information or indeed any other information from remote warehouses will be able to reach the cloud. It will be shown how meaningful data from remote and central warehouses can be captured and stored using readily available networks and cloud infrastructure in Zambia and how that data can be processed in order to produce information vital to the operations of the grain marketing business of FRA. Further, it will be shown how cost-effective remote sensor networks can be deployed for the Food Reserve Agency of Zambia. These sensor networks will be able to work for an acceptably long duration without requiring regular maintenance.

A sensor network will be built as a pilot and proof of concept. The sensors form a mesh network with each other and with the main controller. The shortest path to the main controller is used to relay information from the perimeter devices. In case the main controller is not reachable, the perimeter devices have some level of caching. Perimeter devices always poll the main controller until a connection is formed at which point all the data is transferred to the main controller's storage. This can be thought of as streaming data. The different forms of technology that are brought together to implement the remote sensor network are discussed in detail and finally a prototype of the remote sensor network is shown.

1.3. Motivation and Significance of the Thesis

Currently, the Food Reserve Agency remote warehouses rely on the seasonal members of staff to provide security, accountability and monitoring of the environment. There have been several cases at which stock stored at local warehouses has been destroyed by rain, excessive humidity or even stolen from site. This research will aim at addressing the stated challenges and will introduce automation, enhance accountability and present the possibility of reporting data on demand. Subsequent implementation of a remote sensor network will be the first time cloud services, remote sensing and remote security will be deployed on a government owned programme and possibly in Zambia as a whole. This will lead to more of such networks being used countrywide. It will also ensure that members of staff are exposed to technology as it becomes an everyday tool of use.

1.4. Scope

The scope of this project covered the FRA grain storage facilities in Lusaka and Central provinces. Further, selected warehouses were targeted for reasons ranging from the ease of access, availability of staff to work with, activity at the time of research and importance within the province. These two warehouse locations provided a general picture of the rest of the FRA operations throughout the country. The storage facilities in Lusaka are the largest while the ones in the Central province of Zambia are somewhat representative of the smallest storage facilities.

1.5. Problem Statement

The Food Reserve Agency has a number of challenges in managing the strategic food reserve. The agency, despite being a very important structure in Zambia has lagged behind in the adoption of ICT's. Reports are manually generated which may result in errors and delays, warehouses are not monitored in real time and specialized personnel are required in order to assess the environment at both satellite and main depots. The activities at the Food Reserve Agency are mostly seasonal and hence are managed with just the minimal workforce until the next season. This entails that food storage locations and supply depots have less contact hours with individuals experienced in monitoring the environment at which stock is stored. As an example, it had been clear through preliminary interviews at the FRA Lusaka Mwembeshi depot that 24 hour monitoring of the environment and farmer produce at both the central and remote warehouses is not available. A very good example is when the central warehouses are fumigated and no individual is allowed into the warehouses under any circumstances due to the toxic nature of the chemicals that are used. Further, the 2011 Auditor General's report(Office of the Auditor General 2011) lists the following problems as concerns FRA;

1. Weaknesses in grain management
2. Excess purchase of crops
3. Excess stock losses attributed to spillages, pilferage.
4. Warehouse Management – Poor Stacking making it hard to take stock
5. Poor State of Storage Facilities - Silos

The problems highlighted present huge losses to both government and unmitigated risk in terms of poor food security for the nation at large. It is presented in this paper that all the highlighted problems can be addressed using automation and ICT's (Nancy Mock, Nathan Morrow & Adam Papendieck 2012). It has been shown in other similar research that the use of ICT's introduces efficiency and accountability in agriculture (Masiero 2015). For the purpose of this research, only FRA will be targeted but the solutions presented can be applied to all institutions that deal with warehousing and food storage as well. Against this background, this research will attempt to address the challenges.

1.6. Aim

The main aim of the study is to automate the operations of FRA. It is believed that this will address several grain marketing and storage challenges that FRA currently faces.

1.7. Objectives

1. To conduct a baseline study in order to establish the challenges faced by the manual system of grain marketing, grain storage at FRA.
2. To map the FRA grain marketing and storage business processes and build a model using cloud infrastructure and wireless sensor network in order to address the challenges in (1).
3. To develop a database with a web portal and mobile interface using the model in (2).
4. To develop a remote sensor network for sensing temperature and humidity using the model in (2).

1.8. Research Questions

1. What are some of the challenges faced by FRA through the usage of the manual system for the grain marketing and grain storage?
2. Is it possible to map the current business processes of FRA and develop a model using the cloud architecture and wireless sensor networks in order to address the challenges in (1)?
3. How can we develop a database with a web portal and mobile interface using the model in (2)?
4. To what extent can we develop a remote sensor network for sensing temperature and humidity using the model in (2)?

1.9. Research Contributions

Previous work has already been done by Cynthia Muyunda in her paper on the implementation of an RFID grain inventory management system for the Food Reserve Agency(Muyunda & Phiri 2016). However, further work still remained and the following are the contributions of this thesis;

a) The integration of ISO/IEC and IEEE standards in the business process modelling and software quality assurance phases

b) Integration of GIS functionality to the current business processes
c) Development of the FRA information system based on cloud infrastructure
d) Integration of a remote sensor network using the internet of things concept

1.10. Organisation of the Research

In Chapter one an introduction to the research area and a brief description of the scope of the research is given. In chapter two, through literature, all the technologies that were intended to be used for the research purposes and final product development are examined, we also explore potential technologies that may be used in the future for the development or upgrade of the solution presented. However, common technologies such as the database management system or the use or the programming language are not discussed. In chapter three, the methodology used in the research is explored by considering the different methods used for each of the technical objectives. In chapter 4, the results of the research are looked at and the implemented solutions, models, databases and architecture are presented. Chapter 5 concludes the work where a discussion of the overall research is done and recommendations for the future are proposed.

CHAPTER TWO
LITERATURE REVIEW

2.1. Introduction

In this chapter the technologies that is currently available in mainstream use that will be used in order to achieve the objectives set forth in chapter one are looked at. Aspects of the technologies, processes and standards are discussed in detail in order to give a very good understanding of where the technologies are applied with respect to this thesis. A roadmap of the proposal is presented, and possible future improvements suggested so that the proposal has an evolution timeline and can advance with the changes in available technology. Having a roadmap for change is made possible by implementing the solution with a model that can easily be scalable and basing its implementation on a platform and not a product standard. The difference between a platform and a product are discussed and practical examples based on some of the chosen technology implementations in this work are given.

2.2. Review of Literature

2.2.1. ICT in Strategic Food Reserve

The agricultural activities in Zambia have generally been left behind as concerns the introduction of information and communications technologies. Besides the e-farmer registration system on the Ministry of Agriculture and Livestock web portal and the recent e-voucher(Jere 2015a) system employed by the Farmer Input Support Programme for selected pilot districts, more can be done in order to enhance productivity in the agricultural industry such as geospatial analysis, remote sensing of weather, real time resource monitoring and management, on demand report generation, real-time security breach reporting and tracking of agricultural grants or supplies.

Several counties such as Uganda, South Africa and Nigeria have over the past few years adopted more ICT's in the agricultural sector and these countries have seen a marked improvement in quantities and quality of the harvest to more streamlined supply chain processes(2011). When discussing strategic food reserve, it is important to consider the entire resource train of food production. There are some items that can be purely under the control of man and there are yet others that are not under man's control but associated risks may be mitigated with the available of data and the use of ICT's. An important input into food production and hence food reserve is the climate. Going by the first research question posed as concerns the problems faced by FRA in Zambia, it will be noted later that climate issues play a large role in the quality of the grain that is stored. For example, grain may get spoilt if stored in allocation where there is too much moisture; grain may also spoil if subjected to excessive heat. These are some of the conditions that can be monitored and respective custodians forewarned so that action is taken in a pre-emptive manner.

A lot of research has been done that shows that the effective use of ICT's in strategic food reserve(Armstrong, Diepeveen & Gandhi 2011). Because we are discussing a solution that will make use of ICT's in strategic food reserve, we will explore what those technologies are. We will look at what is available today and what may come. Any solution that is proposed today must be able to work with the coming technological advancements or risk being let unused. As a start, we will look at what cloud computing is. Cloud computing will be used as the basis for the solution being proposed herein. It is therefore important to understand what that technology is and how it may be used for the FRA remote sensor network.

2.2.2. Cloud Computing

With the spread of broadband internet across the globe, more emphasis has been placed on how to effectively and efficiently utilize and allocate all the available computing, processing and storage capacity available globally. A reduction in latency and increased throughput has made it possible for remote computers to be managed and applications run as though they were physically local. Resource sharing has enabled concepts such as Software as a Service, Platform as a Service and Database as a Service where the end user does not need to worry about the technical requirements of systems, software and the technical specifications of the database but just focuses on service usage(Sharma no date). Cloud computing has made it possible for emerging companies to rollout their services at a much faster pace as the cost of datacentres is slowly becoming a non-factor with cloud-based solutions such as Data Centre as a Service (DCaaS).

Cloud computing has brought about novel ideas where a computer is no longer viewed as a standalone entity but can span multiple hardware platforms and multiple geographical locations. A very good example was the so called first world computer Ethereum. The Ethereum platform relies on individual machines spread-out throughout the globe to run a client application with distributed consensus and a distributed ledger. This makes it possible for an application to be installed on the world computer and be able to run even if there was a global disaster of immense proportions. The application is able to run with just one computer that downloaded the entire Blockchain. The Blockchain is a public ledger of all transactions that ever occurred on a distributed network and is termed by many as a disruptive form of technology equivalent to the advent of the internet in the early 1990's. Blockchain technology is perhaps the de facto example of what is entailed by cloud computing as it is a classical implementation of device as a service (DaaS) and software as a service (SaaS) and Ledger as a service (LaaS).

Cloud computing and Blockchain technology have brought about novel modern consumption models such as the shared economy in China. As of 2017, more than 30 billion United States Dollars had been invested into the shared economy in China. The concept behind the share economy is that resources usually tend to lie around dormant when exclusively owned by an individual hence idle time is made best use of by enabling anybody with the means to rent the device for a specified period of time. It can be argued that Cloud Computing is an offshoot or a natural progression of the shared economy model. The shared economy only became possible after the adoption of the electronic market(Zekanovic-Korona & Grzunov 2014). Cloud computing is used as the basis for the FRA remote sensor network in objective 4 of this work because of the benefits associated with managed services. As an organization begins to grow and expand, it is industry practice to outsource those tasks, hardware platforms or services that are not what may be considered the core business of the organization. Cloud computing is therefore very important to look at in detail as regards the possible evolution of the FRA remote sensor network. There are three types of clouds in the cloud computing paradigm and we take a look at each below and the associated advantages.

2.2.2.1. Private Clouds

Private clouds are those owned and managed by a single entity, operation, government or business. Private clouds could involve several types of interconnected infrastructure that is shared within an organization or entity. The argument for private clouds is that they offer security as critical data need not be let out of the confines of the controlling authority. Private cloud may be run by companies, governments or individuals that restrict access to pre-authorised users of the cloud. Figure 1 below shows an example of a private cloud.

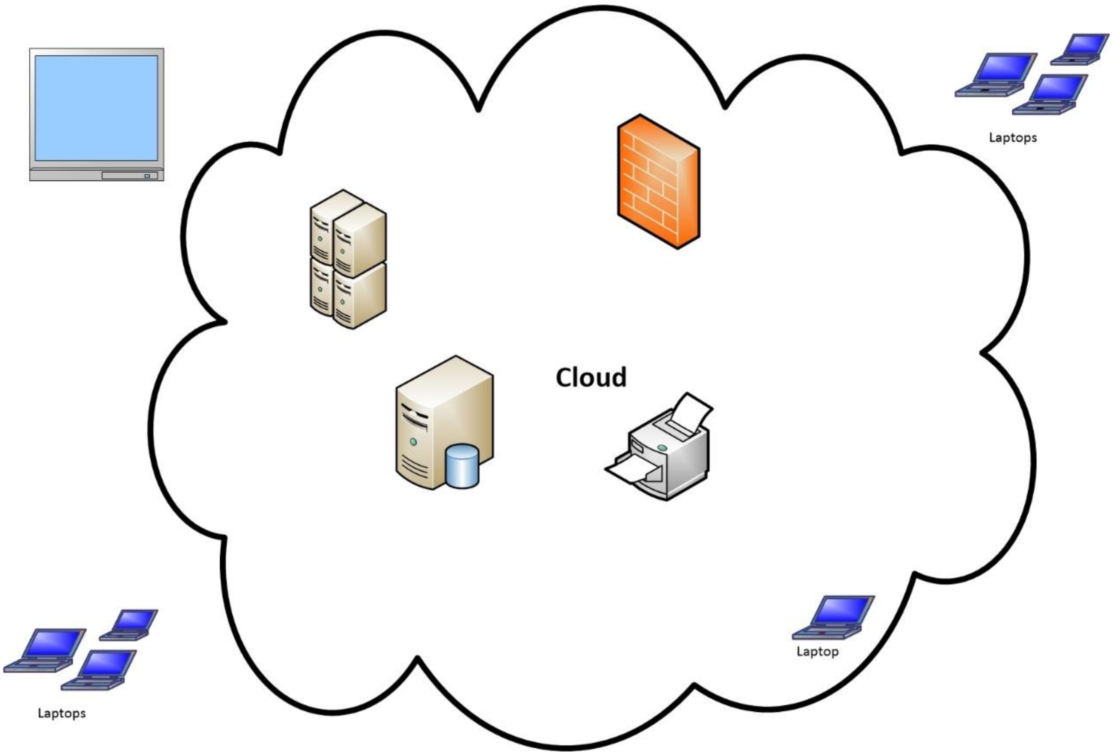

Figure 1 - Private Cloud

2.2.2.2. Public Clouds

Public clouds as the names suggest are cloud services that may be used by any independent authority and shared by others. Public clouds need not necessarily be controlled and managed by a single entity and used by many but they may be composed of various private clouds interlinked though high-speed networks to form a single large cloud with various services managed by various entities. An example of a public cloud is the previously discussed Ethereum world computer. The computer runs over an Ethereum virtual machine which is composed of thousands of instances that run on privately owned computers around the world. The computer may be used by anybody with the requirement that the network is incentivised by a prepayment of tokens termed Ether for the use of the globally available computing resources. Ether may be either bought from pre-existing suppliers or mined by solving cryptographic equations which use computing resources and pay rewards in Ether if the equation is solved. Ethereum has spawned many interesting applications such as Golem which is a distributed machine that can be used by animators to render highly complex computer-generated graphics without having to lease computing resources from specialised proprietors but to lease those resources from the publicly available Ethereum Golem cloud computer. Figure 2 below shows a general high level architecture of a public cloud.

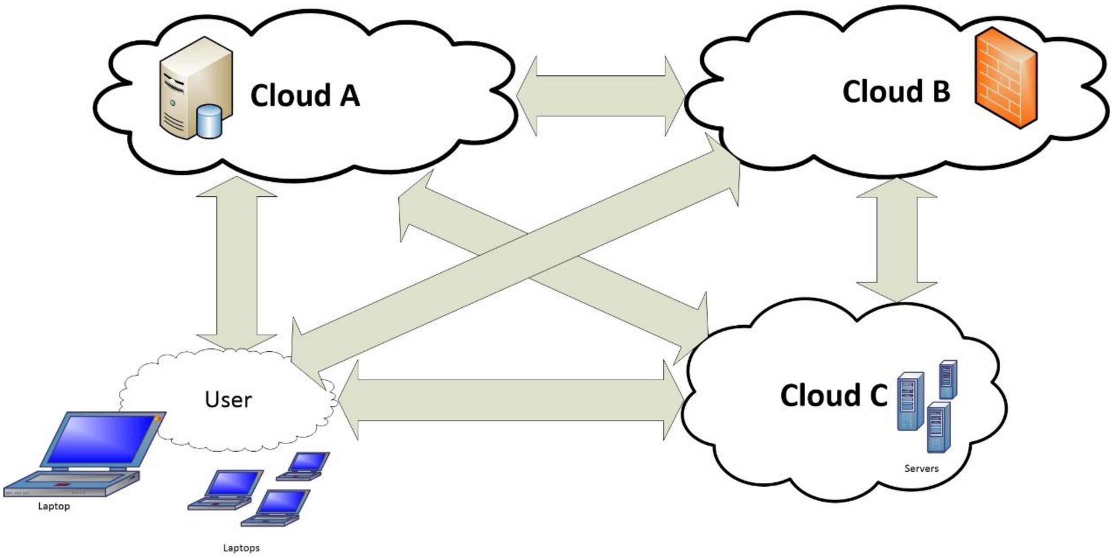

Figure 2 - Public Cloud

2.2.2.2.1. Security on Public Clouds

Because public clouds are used by various independent entities to store, manage and manipulate their independent data, there has to be a way of segregating and masking each entities data. This can easily be achieved via traditional methods that have been used in for example public email hosts such as Gmail and Yahoo. Public/Private key encryption, password protected encryption and challenge/handshake mechanisms can all be applied. The different methods in which security may be provided on the cloud may invalidate the claim by several organizations and governments that information stored on public cloud infrastructure is prone to prying eyes and falling into the wrong hands.

2.2.2.3. Hybrid Clouds

As the name suggests, a hybrid cloud is a combination of a public and private cloud. An entity makes use of both for various reasons such as backing up the private cloud, offering geographic redundancy or optimizing costs and ensuring long term scalability. The most practical use case of a hybrid cloud would be if an entity running a private cloud wished to back up its data on a public cloud with the requirement that all the data running on the public cloud is encrypted first. For a secure FRA backend, we suggest the use of a hybrid cloud approach. Figure 3 below shows the high level topology of a hybrid cloud.

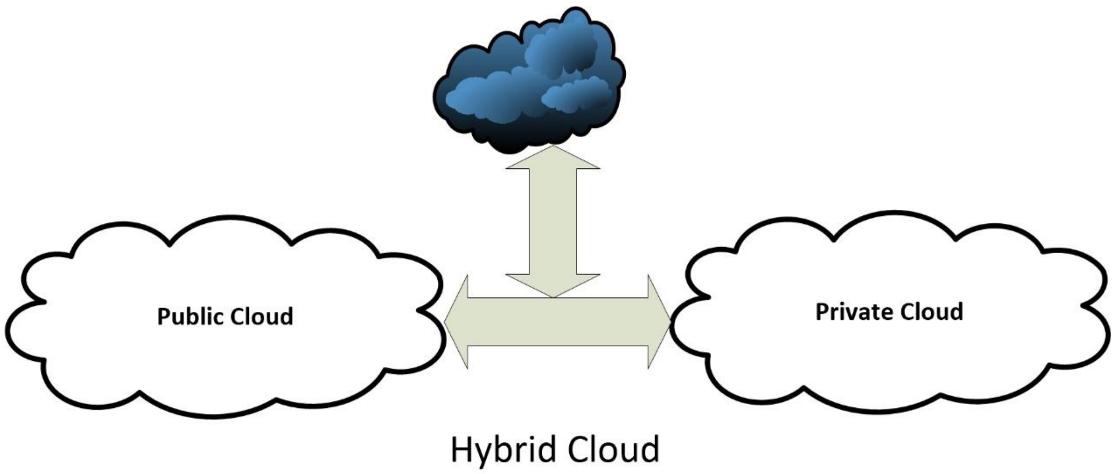

Figure 3 - Hybrid Cloud

2.2.3. Big Data

At the core of IoT is big data. Big data is data that cannot be stored or processed using the traditional means known today, it is data that has generally been disregarded by organizations as there was no means to efficiently store or process it until now. As an example, all the information from all the sensors collected from a smart city would probably not be stored in the past as it would scale to terabytes and possibly petabytes of data in a few days. This is also true in the case of streaming data from the environment such as the real-time temperature and humidity recordings along with various other forms of data including audio and video. The FRA remote sensor network is actually a form of a network that deals with big data(Yan et al. 2014). Also, the traditional relational databases cannot scale to meet such demands.

As another example, big data about an organization may contain all the conversations that have occurred in the last year between employees within the confines on the organization. Within a given timeframe, if one wanted to find a particular conversation between person A and B that referenced a certain topic, one could imagine that the information might be contained within a database. However, what is being referenced is hours and hours of perhaps MP3 data. This data obviously holds a lot of valuable information which may not have otherwise been captured in say email conversations or indeed company enterprise resource planning systems. The previous example essentially highlights what may be termed as big data. Organizations have come to realise the potential of big data in strategic decision making. The difference today between successful organizations and those that fail to make it lies in how effectively an organization uses its data and indeed its big data (Hakan Özkösea et al. 2015). In the deployment of smart water management systems, the issues surrounding big data would have to be dealt with. There would be so much information being captured in structured and unstructured formats which may need to be processed and analysed. Fortunately, there are open source systems such as Hadoop and Map Reduce which may be used in order to manage big data. Recent solutions such as Blockchain technology and the use of national data centres have also been suggested(Chibuye & Phiri 2017).

2.2.4. Blockchain

A Blockchain is an immutable public ledger of all transactions that have ever happened in a system. Blockchain relies on private/public key cryptography in order to achieve the immutability of stored records. While past records may not be changed, future records can link to past records with transactions thereby making a recent changed copy of a past record. The beauty about Blockchain is that it leaves an audit trail. It is possible to erase all past records in a Blockchain using a consensus algorithm whereby all participating systems within a Blockchain agree to change a record in the past and replay all future transactions after the change. Fortunately, there will be an audit trail of a past record having been altered.

While there may be a concern as to how secure a public Blockchain would be in keeping what may be termed sensitive data, there exists advanced encryption standards such as the BB84 protocol that can be applied. This protocol makes it mathematically very hard to break the encryption code. An argument is put forth that information stored digitally and securely is safer than information stored in an office and on a file that prying eyes can have access to(Johnston & Bowen 2005). Information stored on file has the following risks;

- Third party access
- Files accidently left in an unsecure location
- Ease of duplication
- Natural disasters
    - Fire
    - Floods
- Theft
- Trust

With Blockchain Technology, only the user with access to the private key may have access to the files, the private key may also be further encrypted with a password. Also, it is possible to implement multi key signatures for approval hierarchies where more than one user is required to approve a transaction.

2.2.4.1. Benefits of Blockchain in Data Storage

It has already been noted as to the broad benefits of Blockchain technology but here we look at the specific benefits to the quest for government's world over to implement national data centres.

Blockchain technology allows for the storage of data on every participating party's system hence offering unparalleled redundancy. They also offer the possibility of the implementation of smart contracts which are defined as peer to peer arguments enforced by code on a Blockchain network. These smart contracts can do many things such as copy and manipulate data that is stored on a Blockchain. The network can be sponsored by untrusted parties because only the user with a corresponding private key has access to data that was encrypted with a public key. It is even possible for a public/private key combination corresponding to a certain data set to be changed every time a transaction occurs on a Blockchain network. There are various possibilities of implementation of a Blockchain network and its characteristics are far superior to the traditional databases as used in cloud computing today. Blockchain technology is true infrastructure as a service, storage as a service and data manipulation as a service.

2.2.4.2. Benefits of Blockchain to Governments

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2.2.4.3. Big O of Data Storage, Access and Manipulation

The big O notation is the standard method of analyzing the performance or complexity of an algorithm. Given that the ideal national data centre is required to host all the government data requirements from each of its institutions in a decentralized manner; it can be argued that the storage and analysis of data becomes a complex activity. E-government projects are primarily concerned with big data and according to the United Nations 2016 E-government survey report, the 2030 sustainable development goals have at their coal an open and inclusive government with big data available for interpretation by citizens and the world in general(2016a). Storing and analyzing big data brings inherent storage and processing complexity. In big O notation, we refer to the storage and analysis complexity as space and time complexity respectively.

Because the nature of a data centre is to have high availability and data redundancy, there will be multiple instances of big data stored on servers which increases the data access and storage algorithm complexity(Yuan et al. 2010). With decentralized storage, the order of magnitude of computational complexity becomes exponential unless parallel search algorithms are deployed. It has been shown that multiple sources of data and parallel search algorithms reduce the space and time complexity of big data hence providing a more efficient big O rating(Yan et al. 2014). Because Blockchain are distributed ledgers they are an alternative implementation to clouds, centralized storage systems and national data centres, there has been a several research items dedicated towards improving the time and space complexity if used as a distributed database(Aniello et al. 2017) and for reasons previously highlighted, we recommend that Blockchain technology is further explored as concerns the data storage requirements of FRA. However, for the purposes of this research, a relational database has been developed and it is our hope that future research will explore the evolution towards a more decentralized and possibly Blockchain approach.

2.2.5. National Data Centres

National data centres are a basic requirement in e-governments across the world. The traditional models of running government worldwide have remained unchanged despite the advancements in data science and storage technologies. In the 1990's Government Process Reengineering which relied on Business Process Reengineering was proposed as a method to lead to leaner and more efficient governments(Li & Yang 2016). This naturally led to what was termed the information-based government which also evolved to the current e-government being implemented in most counties across the world.

In order to introduce efficiencies into the running of government institutions and avoid the duplication, unnecessary storage of data and global sustainable development goals as set forth by the United Nations, governments around the world have embarked on e-government projects. A typical example is the government of Zambia which has embarked on the e-government project which is a $440 million(Brain 2017b) project that aims to connect all government offices with 12,000km(2017c) of fiber using a FTTB(fiber to the building) model. These individual units will then have access to a common data centre where all data will be stored. The case of the Zambia national data centre is used as a generic model for most national data centres worldwide. Since Zambia already has a national data centre, the commercial application of the remote sensor network can make use of the existing facilities. However, it ws evident through this research that the national data centre model may just be the beginning of the progression towards more privatized and outsourced models. Below we look at the evolution of national data centres by exploring some noteworthy cases.

2.2.6. Case Studies – National Data Centres

In this section we first take a look at the Zambia national date centre and then consider an example of the history and current status of national data centres from the United States.

2.2.6.1. The Zambia National Data Centre

The Zambia National Data Centre (NDC) is an initiative by the government of Zambia to deploy cloud infrastructure to be used for the following services;

- Infrastructure-as-a-Service
- Storage-as-Service - SaaS
- Backup-as-a-Service
- Disaster-Recovery-as-a-Service DRaaS
- Software-as-a-Service

The main purpose of the Zambia National Data Centre which is managed by Center of Excellence for e-Government and ICT, a wing of the Ministry of Communications and Transport is to consolidate government ICT resources hence introduce efficiencies in the acquisition, management and maintenance of those resources. Figure 4 below is a summary from the Ministry of Finance and National Planning page on the goals of the project.

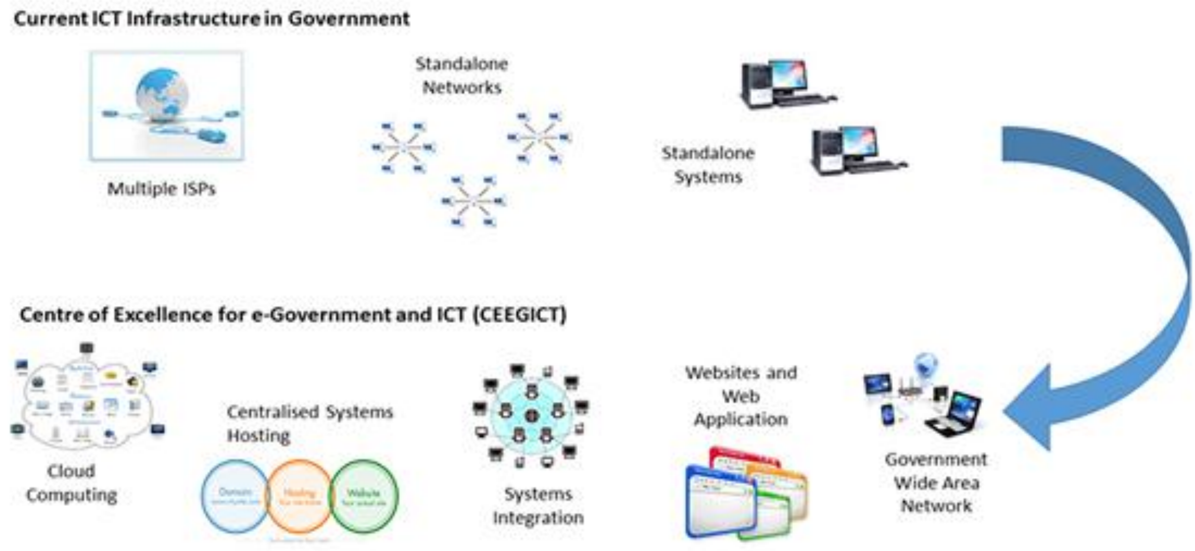

Figure 4 - Overview of the Zambia National Data Centre (Ministry of Finance and National Planning, 2016)

From a redundancy and resilience point of view, we can already note that centralized system hosting presents significant future challenges for this project. It is quite possible that the government will build a tier IV data centre that provides active redundant components as concerns power and cooling, but this does not protect from localized geographic force majeure.

The current implementation of the Zambia National data is an example of a centralized approach towards national data centre implementation. By examining the case of a more advanced economy already making use of data centres in government, we can have an idea as to the possible glide path of the Zambia National Data Centre. We consider the case of a more advanced data centre implementation in the United States prior to the terrorist attacks of September 11, 2001 under the Department of Homeland Security. The United States Department of Homeland Security Data Centres were picked as a case study because they were the first data centres in the United States to undergo optimization projects.

2.2.6.2. The United States Department of Homeland Security National Data Centre

Prior to 2001, the United States government's department of homeland security had several data centres spread out in various areas of the country. According to a report on data centre consolidation by the department of homeland security, part of the reason for the success of the mission set forth by the department was "integrating the incumbent workforce, processes, and systems into a unified organization"(United States Department of Homeland Security 2011). In the case of systems, these were related to the various data centres spread out throughout the country. The data centres were linked by 7 individual wide area networks. It was noted that despite the advances in e-government, there remained one fundamental problem which led to inefficiencies in collaboration amongst government stakeholders following the 2001 terrorist attacks an according the report these are highlighted below;

- Limited corporation
- Limited communication
- Limited data sharing
- Limited protection

It was therefore decided by the United State Government that a data centre consolidation project be undertaken in order to address the inefficiencies highlighted above. These consolidations would however maintain the basic requirements of distributed cloud architecture and bring about the following benefits;

- Significant operational cost reduction of more than $200m per year
- Standardizing IT resources
- Streamlining maintenance
- Expediting response times in case of emergencies

The United States Government has not ended its optimization campaign and through two more iterations, several government organizations are now implementing the Federal Data Center Consolidation Initiative(United States Department of Homeland Security 2011). We discuss this data centre issue to bring to mind that despite having reasonable goals in data centre implementation, without proper case studies, resources may be wasted through further optimization such as with consolidation projects. We also wish to bring to mind that there may be other alternatives to national data centre deployment such as cloud based or Blockchain based national data centres that have been previously discussed. It is important that careful analysis of these case studies is done by the Zambian Government in order to ensure smooth operations now and in the future.

2.2.7. The Internet of Things

The internet of things(IoT) is a concept that defines what is termed as the future of the internet(Khan et al. 2012). The internet in this vein is no longer viewed as a set of computers hosting applications that can be accessed by other computers as the original definition stated. In order to distinguish the current revolution, the "Internet of Things" term was coined to represent all devices that need to interact with other devices on the internet using low power and low communication protocols besides the traditional computer. It is envisioned that in the future, even devices such as doors, windows, shoes, clothes, or anything one may think of that can provide a digital service or can be controlled or used remotely via the internet, will be connected to a world grid and be able to send and receive information relevant to it. Current technology is making leapfrogs in order to make a ubiquitous network a possibility. The data collected from the IoT devices such as meters and sensors need to be transmitted to, collected and stored in a cloud-based location. There are various transmission media available in Zambia such as Wireless broadband (Wi-Fi) networks, fibre cable networks, satellite communication and mobile broadband. Mobile broadband is most pervasive which makes it an attractive media for interconnectivity of the digital tools on the water network allowing for ease of integration of customer devices and meters to the digital water network. The mobile communications services available in Zambia that provide various capabilities that are able to support IoT solutions include 2G, 3G, Long Term Evolution (LTE) and Virtual Private Networks (VPN) platforms. In the 2017 financial year of Zambia, mobile subscription significantly shot up to cross the 13 million subscriber-mark, all the way to 13.4 million. This was from a previous subscription of 12 million in 2016. This represents an 11.8 percent rise in the number of mobile subscribers in Zambia. The increase in subscription was accompanied by a 2.8 percent increase in the mobile penetration, which moved from 79.1 percent in December 2016 to 81.9 percent in December 2017 (Zambia Information and Comunications Technology Agency 2017) as shown in Figure 5. The proliferation of subscribers and mobile network penetration entails that new areas are serviced that previously had no mobile network coverage. This is an important factor as we consider rolling out a remote sensor network. Mobile internet connectivity will play a crucial role.

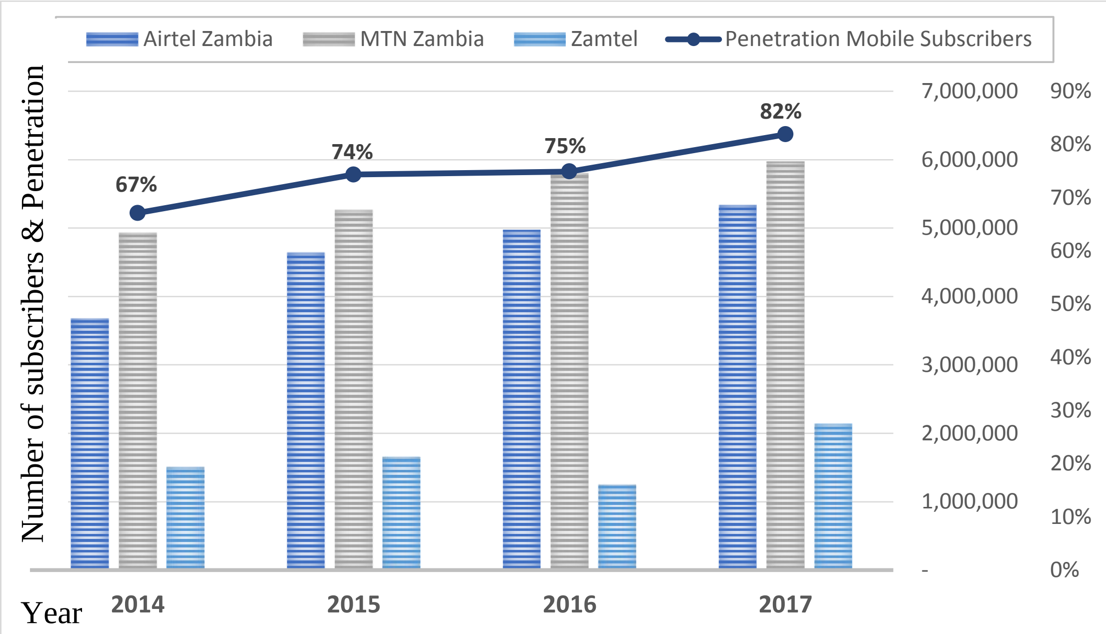

Figure 5 - Mobile Network Subscription in Zambia, 2014 – 2017

Source: Zambia Information and Communications Technology Authority (ZICTA)

The emergent of cloud computing services provides a solution for decentralised data storage and mass analysis. Cloud computing is gaining prominence in the country with more entities structuring their business models around providing such infrastructure and related services. Information derived from Zambia Information and Communications Technology Authority (ZICTA) indicates that there are only two entities that are fully specialised to provide data storage facilities: Netone and the Zambia National Data Centre (ZNDC) previously discussed. Other entities also provide data storage services as value added services (VAS). These facilities provide the means to collect, store and quickly analyse the enormous amount of information that would be potentially generated from the IoT devices.

One of the obvious things that one may think of is that in order for a concept such as the Internet of Things to make sense on a global or universal scale, there would have to be a global network which supports that. There are projects that are being carried out by organizations such as Facebook which plans to beam down internet using laser beams throughout the globe from low orbit solar powered aircrafts(Chandrasekharan et al. 2016) and the OneWeb® project which plans to bean down 2G, 3G and LTE networks throughout the globe(Lee 2016). It is expected that proposal such as the Food Reserve Agency ‘s remote sensor network will greatly benefit from the proliferation of the global networks especially as concerns areas that are currently not covered by the incumbent telecommunications companies.

Another problem that will need to be managed if billions of devices will be able to communicate with each other over a global network is the public address scheme(Durvy et al. 2008). The most popular protocol in use today is the TCP/IP stack. The poplar IPV4 will soon become obsolete and IPV6 will be the standard communication protocol in use on the internet according to the RFC1883 specification, refer to appendix F for a snippet of the specification. IPV6 makes it possible for all the grains of sand on this planet to have an IP address hence the addressing problem is solved. A third very important problem that is being addressed in readiness for the revolution is the power requirements of devices. There has been significant research in terms of improving battery power of devices but for the current practical purposes, reducing the power requirements of active components is the most common method used in order to prolong battery life. Technologies such as Zigbee(Wang Qin Chen Zhonghui Chen Xin 2009) which can run for months on a single AA battery are usually adopted as the standard for use in remote networks where devices need localized communication. A systems designer therefore only needs to focus on providing significant power resources to the main communications device which uses a public network in order to gather, aggregate and send localized information from multiple sensors or “Things” within its vicinity.

2.2.8. The Shared Economy

By its definition, the shared economy aims to make optimal use of resources. Since the premise on cloud computing is also optimizing resources, we infer that a natural evolution of cloud technology is towards the shared economy(Sun, Yan & Zhang 2016). With concepts such as the internet of things, it becomes possible to implement machine to machine (M2M) communication in a trustless manner because computer code will never lie and will always follow the programmed algorithm unless it is programmed as artificial intelligence neural networks with autonomy. Classic implementations of the shared economy include Airbnb(Zekanovic-Korona & Grzunov 2014) where hospitality is abstracted as a “thing” on the cloud and the rent a bicycle concept in China where each bicycle is a “things” and supports machine to machine communication(Flüchter & Wortmann 2014). End beneficiaries use a mobile app to get permission to the use of either an apartment in the case of Airbnb or a bicycle in case of the e-bike in China. As the government of Zambia begins to implement cloud technology, we can argue that the implementation will naturally progress towards an optimal and cost-effective model leading to the shared economy model. We foresee a time when remote sensors in a network will be able to manage their own resources such as paying for network access using some sort of incentive system(Strugar et al. 2018).

2.2.9. Grain warehouse management systems

Grain warehouse management is a standardized process and the Food and Agricultural Organization unit of the United Nations has specific requirements set out to guide the construction and operation of such facilities (1994d). It cannot be ascertained as to whether the Food Reserve Agency adheres to those standards hence matters related to the suitability of the environment at which grain is stored are part of the objectives of this research. As we design a system to monitor the warehouses, we will ensure that our objectives are aligned to FAO and ISO standards. Appendix E lists some technical requirements for grain storage with examples of wheat and maize. As another example from the ISO 6322-2:2000 standard that relates to Storage of cereals and pulses, ventilation requirements for cereals and pulses (crops such as beans) are clearly specified. It is not possible to adhere to those standards without deliberate management of environmental conditions and the solution presented will monitor environmental conditions such as the temperature, humidity and the pressure.

2.2.10. Wireless Protocols

Technologies such as remote sensor network rely on various types of sensors that need to either communicate with each other or communicate with a master controller or a main controller. In order to optimize resources, a main controller is usually the only device that has access to either a public or private network, the publicly available network is required in order for a master controller to relay information to the cloud. The master controller is responsible for aggregating messages or data from various sensors under its control to the uplink which in the context of this research is a cloud-based database. The choice of which wireless network to use should be based on organizational objectives as such as the budget for power, data throughput requirements(whether information such as voice or video will be relayed), security requirements and of course availability of the technology. Here, we discuss the various types of wireless protocols in use today and one yet to be commercially deployed in many parts of the world. We look at the merits and demerits of each.

2.2.10.1. Zigbee

Zigbee is a low power wireless protocol operating at layer 2 of the OSI protocol stack using the IEEE 802.15.4 standard(2016b:15). Zigbee is primarily used in the local area network of a remote sensor network. Because of its usually limited reach as concerns the wireless signal, it is further classified into a set of wireless personal area networks (WPAN). The protocol can be used to send small payloads between a sensor and its controller. Because of its design focusing on low computational complexity, it is ideal in the deployment of sensor networks communications requirements. Zigbee will be a very important part of the proposed implementation as concerned with the one of the primary goals of achieving a power efficient implementation. Zigbee is not a standardized protocol but has reached maturity in industry. Zigbee devices can be setup and configured in three distinct modes, coordinators, routers and end devices. There can only be one coordinator in a Zigbee network and this will usually be connected to a device that has access to the backhauling network. Router devices as the name suggests, aim to forward packets or frames to the targeted device while end devices are passive and only send/receive data within the cloud setup. Zigbee data can be converted to a different protocol by the use of a Zigbee gateway which is part of the standard architecture. This protocol conversion is important in remote sensor network scenarios when sending wireless sensor network aggregated data to a remote server over a different wide area network that operates on a completely different protocol stack. A Zigbee network can be set up in multiple types of topologies namely the start, tree, mesh and clustered tree topology.

2.2.10.2. Low Energy Bluetooth

Low energy Bluetooth or BLE is a wireless technology that is also widely deployed for personal area networks. This is a viable substitute for the much widely used Zigbee. The advantage of low energy Bluetooth over Zigbee is that it uses much lower power per bit of information as compared to Zigbee(Siekkinen et al. 2012). We also believe that as the standard further develops, we could see further improvements in the power efficiency. The major disadvantage is that it is a master/slave type network hence the typical deployment is a start topology. We consider it for our research primarily due to its advantages as concerns power and we believe it can be used to substitute our Zigbee implementation where required.

2.2.10.3. GSM (Global System for Mobile)

GSM is the first ever digital format for the operation of wireless mobile phones. GSM relies on both frequency division multiple access and time division multiple access. The original purpose of this technology was just to support mobile, wireless voice calls. As with any network that becomes ubiquitous, a use case emerged for the transmitting of data over GSM which led to the so called 2G or second generation of GSM. This version supported data though with minimal throughput.

2.2.10.4. 3G

3G is based on completely different technology from its predecessor GSM and 2.5G in that it relies on coded information over the same frequency. This has the obvious benefit of crunching as much data as possible into available frequency allocation. Certain laws have to be obeyed though such as the Shannon Law which limits the theoretical maximum throughput that a transmission system may support. 3G or 3rd generation technology used wideband code division multiple access and the fundamental principle for sending data over the air interface. This has the added advantage that 3G technology can squeeze more data through an assigned frequency spot. There are of course other forms of 3G which use less popular coding schemes such as code division multiple accesses 2000, CDMA2000 popularly used in North America but the principal is similar. 3rd generation mobile technology cannot necessarily be differentiated based on the allocated frequency spectrum because it is not uncommon to see 3G being deployed over traditional GSM frequency spectrum.

2.2.10.5. 4G and LTE

LTE stands for Long Term Evolution while 4G stands for 4th generation mobile technologies. The two terms are generally classified as the next upgrade from 3G networks. While GSM and 3G relied on circuit switched components within the system. LTE and 4G technologies rely purely of packet switched networks usually referred to as Internet Protocol or IP networks. They are a combination of technologies that are used in GSM and 3G. LTE is usually referred to as 4G by several individuals, organizations and telecommunication companies but there are notable differences as defined by the 4G or 4th generation standard. 4G is a lose technical term used for LTE-Advanced network or International Mobile Telecommunications Advanced (IMT-Advanced). The LTE standard was coined in 2008 while the LTE-Advanced standard was defined and became an ITU-R standard in 2010. LTE-Advanced or 4G offers much higher throughput and several enhancements on top of regular LTE. Currently several operators around the world support LTE but very few operators support 4G or IMT-Advanced. For the purposes of our remote sensor network, we will support the use of 2G, 3G and 4G networks as the public uplink provider while Wireless Fidelity discussed below is used as an alternative to Zigbee though both can be interchangeable.

2.2.10.6. Wireless Fidelity

Wi-Fi® is a registered trademark and technology name given to a set of wireless network access protocols. The trademark is owned by the Wi-Fi Alliance and is commonly used to certify products that have passed industry specified interoperability testing. Wi-Fi is an acronym for wireless fidelity. First developed as the 802.11 standard, it is an IEEE standard and is mature. Wi-Fi is commonly known as the ether that provides internet connectivity for computers and smartphones. However, it can also be very useful in remote sensor networks as its features work well in today’s IP version 4 world. Wi-Fi tends to be accessible via what is termed a wireless access point. The wireless access point is essentially the master of the network and assigns IP addresses to all slave devices. The slaves need to communicate with the Wi-Fi access point before being able to reach the internet or an intranet.

2.2.10.7. 5G

There is currently a global race to determine what the standards will be for the next generation of mobile telecommunications termed 5G or Fifth Generation. 5G will support speeds of at least 10Gbps on the downlink and will entail a complete overhaul of the existing infrastructure. 5G was designed and envisioned with the connected world and the internet of things in mind. It will support network level functions such as network function virtualization or NFV, Software Defined Networking or SDN and IPV6 as being the primary addressing scheme. In order to have the Internet of Things really be able to connect billions and billions of things, the traditional base station in the telecommunications network will have to be able to route and transmit several gigabits of data. In a practical way, certain functions of the public mobile network will have to move to the edge. Solutions such as caching of data, predictive algorithms and localized routing will play a major role in 5G networks. 5G networks will be an interesting addition to the wireless sensor network world because it might not be necessary to use a combination of a localised routing network such as Zigbee and 5G as the latter is able to handle the localised routing part.

2.2.11. Remote Connectivity Challenges

When we discuss wireless sensor networks and the Internet of Things (IoT), certain fundamental problems arise and these will have to be addressed. In the context of a simple sensor network, the traditional setup would require a main controller that has some sort of wireless protocol shield that is used for remote communication. The main controller may or may not process data that has been received from its slave sensors. The details of the implementation are usually up to certain preconditions such as; the availability of power, reliable network connectivity, available computing resources and generally the mode of implementation such as a partially decentralised, centralised or distributed architecture. In the case of a single main controller that aggregates the data from multiple slave devices, we may only require a single point of entry to the sensor network and access each slave via that single-entry point. In the context of a single-entry point and private sensor networks, we would require a public IP address to be configured on the main controller so that it can be accessed remotely by its unique identity. In the currently popular IPV4 standard, it can be argued that there would not be sufficient IP addresses available in order to assign public addresses to each device in a sensor network. The IPV4 standard only maintains a list of only 4 billion(Babatunde & Al-Debagy 2014) public hosts because of its 32bit address space. According to the World Economic Forum's Global Information Technology Report 2016 which is published in partnership with Cornell University, by 2019, there will exist more than 2 billion internet users(Silja Baller, Soumitra Dutta & Bruno Lanvin 2016) not to mention the number of projected machines that will require connection to the internet due to machine to machine communication (M2M) and the recent requirements by the internet numbering authorities for all mobile devices that use the internet to have a unique public IP address. Fortunately, there will a migration towards IPV6 which maintains a 128bit address space or enough IP addresses to assign a public address to every grain of sand on planet earth. While there have been methods to extend the address space by using network address translation commonly referred to as nating, the practicality and its importance is being diminished by the need for devices to be able to communicate publicly and to be identified uniquely.

The arrival of IPV6 has been a very practical prerequisite towards the rollout of wireless sensor networks. It will be possible to assign a unique IP address to every device capable of running a supported wireless protocol that can be configured with layer 3 addresses.

2.2.11.1.1. Communication over a Private Network

Because the remote sensor network is by its definition going to be deployed in areas that are some geographically significant distance from where the data is transmitted to, stored and processed, there has to be a mechanism of communication over that vast geographical coverage. We have already discussed the type of common wireless technologies that can be used such as GSM and 3G. As of this writing some of the operators of these public networks do not abide by the requirements of the internet numbering authorities to assign public IP addresses to each SIM card that uses their network. Even in cases where public IP addresses are used, the provider of the network may employ the use of firewalls in order to limit access to their customers' devices from outside the confines of the network. In the implementation of our remote sensor network, we want to be agnostic to the underlying provider of the communications network and we would like to be able to switch the providers at will without having to change the code or communications settings on our devices. The communications network should be transparent to the remote sensor network. There are several methods that can be employed in order to address the challenge of communicating over a network that we do not have control over.

2.2.11.1.2. Using a Central Server

Using a central server is perhaps the easiest way to manage a scenario in which the network provider either uses a private address space or uses a firewall to block external network access to customers of their network. Using a central server means that only the main controller, of all controllers in the sensor network are configured with a public uplink address or an address to which they communicate with. This is typical in the client server architecture commonly used on the web today. Each device simply collects and/or processes its data before sending to that central server.

2.2.11.1.3. Using Dynamic DNS

DNS or domain name service is a method employed over the internet or cloud in order to assign a qualified name to an internet address which may be an IPv4 or IPv6 address. This makes it easy for humans to type in address into a browser or application by using their native alphabet. DNS supports Unicode hence characters in almost every language on earth are supported. Usually, the domain name is assigned statically to one or more IP addresses. Dynamic DNS is a method that is employed in the case in which the provider of the network assigns dynamic IP address to customers on their network. IN this case, the remote sensor network devices are assigned domain names which are linked to dynamically changing IP addresses by software that is running on each node or on the main controller. For the purposes of power optimization, the dynamic DNS software may only be run on the main controller and the communication between the main controller and individual sensors kept local in a master/slave setup.

2.2.12. Global Positioning System

The Global Positioning System (GPS) has achieved mainstream and widespread adoption. It has become a ubiquitous part of daily life from being imbedded into smart phones to its use in navigation and mapping. The Global Positioning System being the most popular form of geolocation technology in use today will be a very important part of our sensor network architecture. We will need to be able to determine the exact location from which our sensors are sending data over a publicly available IoT gateway or wireless network such as 2G, 3G or LTE networks previously discussed.

GPS was developed by the United States Department of Defence (DoD) in early 1970 under DARPA for use in navigation during military exercises. In the late 1980's, this technology was released for public use and is free of charge. GPS uses a constellation of 24 satellites with 10 being always visible to device anywhere in the world. GPS works everywhere and in any weather condition as long as the sky is visible. The availability of GPS has seen a widespread development of many applications. GPS is currently more than 47 years old. In recent years, there has been widespread research into the next possible successor of this technology. Various projects exist such as the OneWeb® project, Googles satellite project and the Iridium project. These new geo location technologies provide other features unavailable in GPS such as combining internet and geolocation information within one packet which reduces the complexity in design of the end user devices. Such networks will be an added advantage as sensor networks begin to take centre stage the world over.
While there may exist several global tracking and telemetry technologies in use or development, systems such as the one we are building will benefit from a non-commercial/civilian technology for reasons such as cost optimization and technical maturity.

2.2.13. Power Management

Since the remote sensors need to communicate with aggregators, central controllers and possibly central or cloud based backends, several questions arise as concerns the power requirements of the sensors. In order to optimize the power resource, low power solutions are usually deployed. In the case of inter sensor communications, the code running the logic on the sensor device can be optimized to only work when certain conditions are met. For example, if it known as to how much power a sensor produces when it performs its intended work, the code could be optimized such that the work is only done at predetermined times. A good analogy is when sampling analogue signals, one could determine the best sampling frequency to use using the Nyquist theory so that vital information is not lost and the intended signal is easily reconstructed. Sensors are basically used in order to capture environmental data and possibly be able to determine or simulate the conditions of the environment at a desired time hence it can be thought of as sampling the environment. It is important to determine what the sampling intervals will be, how much power the sampling uses and how much power is used when the sensors and aggregators are in idle mode. From there, it is possible to come up with a power budget and determine the actual investment required. Deliberate protocols that are designed for power efficiency are already available for use in building remote sensor networks. Below we take a look a popular protocol called MQTT.

2.2.14. Mobile Queuing Telephony and Telemetry (MQTT)

MQTT stands for Message Queuing Telemetry Transport. The MQTT protocol is specifically designed for IoT devices with low bandwidth requirements. It is a lightweight publish/subscribe protocol over TCP/IP with a level of quality of service defined and was originally created by IBM and Arcom(Hunkeler, Truong & Stanford-Clark 2008). It has since become an ISO standard with filing ISO/IEC 20922:2016(2016e). It is ideal for mobile applications because of its small size, low power usage, minimized data packets, and efficient distribution of information to one or many receivers. In the previous section, we looked at the importance of managing power in remote sensor networks and the MQTT protocol was built with that in mind. A specific implementation of MQTT for sensor networks is called MQTT-SN (Message Queuing Telemetry Transport for Sensor Networks). MQTT is a variation of Zigbee(Nidhi Patel, Hiren Kathiriya & Arjav Bavarva no date). The MQTT protocol needs to be implemented by any server or cloud service claiming to support IoT applications. In our work, we considered both the Mosquitto open source broker and the proprietary Amazon Web Services (AWS).

2.2.15. Mosquitto Broker

In the typical architecture of an internet of things project, we have the “Thing” which is a device connected to the internet that can be sensor or an actuator which performs an action and we also have the broker which can be a centralized or cloud based system that publishes messages to what are called topics. Each of the “Things” in an internet of things setup subscribes to a topic and each topic can cover a specific need or requirement such as a topic to control lights at the end of the day in a specified geographic region. The broker can publish a message to switch on lights in a specific geographic area and any switch that can be viewed as a thing that is subscribed to the switch topic will flip the switch to on. The Mosquito Broker is an open source broker that is used in internet of things applications and was our selection for our model. The Mosquitto broker implements the mobile queuing telephony and telemetry protocol version 3.1 as of this writing. Version 3.1.1 of the broker was specifically designed with internet of things applications in mind as it implements a light weight publish/subscribe methodology.

2.2.16. Android Things

Having looked at important aspects making up the IoT architecture, it is also important to consider how the remote IoT setup is managed and controlled. This brings us to a review of Android Things by Google. In a nutshell, Android Things is an operating system for IoT applications. In order to understand the importance of the Android Things OS, a little background as to how sensor networks have been built in the past will be of practical assistance.

The most popular standard for the implementation of internet of things prototypes and solutions has been to use the Raspberry Pi and Arduino with various sensors and custom code which can vary dramatically from one form of implementation to another, with so many different types of sensors available, each one of them would also require a careful study of the datasheet and tireless efforts into designing and implementing drivers for various platforms. Manufacturers would generally leave the coding and definition of drivers to the interested parties. This obviously brings about issues related to duplicated efforts as one developer in one part of the world and another in a different part both work on the same driver that would accomplish the same task. Fortunately, the open source community and code repository platforms such as GitHub have made sharing and publicity easy so that before one would undertake on a programming venture, one would first have to analyse existing code in order to prevent unnecessary work. As concerns the development of a wireless sensor network, one would then have to attach GSM , Wi-Fi or some other wireless protocol shield in order to achieve remote connection to either a distributed or a centralized server, there has been several attempts at creating sensor networks that use a mobile device for obvious reasons of taking advantage of the use of a mobile phone and that is to send and receive data(Piyare & Piyare 2013). Mobile phones have become really powerful device and can be termed as massively integrated computers. Modern high-end devices can typically be composed of one or more sensors the most common being gyroscopes, orientation, proximity sensors, accelerometers and biometric sensors. When considering the capabilities of mobile phones, an interesting question to ask may be what else can the phone be used for besides personal communication and entertainment? In recent times, phones have become personal wallets and have even used by companies for the purpose of crowdsensing(Ganti, Ye & Lei 2011). What makes a phone suitable for sensing? If a smart phone is to be considered, it basically has an operating system in which custom applications may be installed. A phone may also have one or more interfaces such as a USB 2.0 connection that can be used to connect it to other devices even if those devices do not support the USB 2.0 protocol. If a device does not support the USB protocol, some form of adapter may be used in order to translate the USB protocol to say the serial protocol. However, if a smartphone is to be used in order to develop a sensor network, cost considerations would become a major blocking point. On average, a smartphone containing basic sensors such as temperature, humidity and pressure can cost in the range of between $500 and $1,000. When discussing low cost internet of things applications and devices, those costs are too high. Not to mention the power requirements that most smartphones have. On average, the battery for a smartphone will not last more than one day with the network functionality on and so many background activities in operation. A way to make the smartphone more optimal would be remove unnecessary applications and limit background activity to only the essential or required one, this however does little to make the device less power intensive, studies have shown that typical energy saving mechanisms on smartphones do little to preserve battery life(Kim et al. 2014). It should be realised that when talking about internet of things applications, it is common to want devices that would be able to work for months on cheap standard batteries, the definition of cheap may however be a subjective term and in order to make it more objective, a power budget analysis may have to be done for the system of concern. As battery technology further improves, several thousand ampere hours could be packed in a tiny battery. Android Things aims to address the issues raised above through leveraging already existing hardware platforms and development environments by installing an operating system on those devices that support the basic computing architecture as we understand it today. In the most basic of terms, the mobile phone may be described as a system on module with peripherals attached. This may not be so different from the computer architecture which defines several components such as the central processing unit, arithmetic and logic unit, bus and provision for peripherals. That operating system called Android Things is built with an internet of things architecture at its core and therefore supports native functions and routines that make implementing a prototype or developing a solution a very easy thing to achieve. There is no requirement to write code for multiple devices such as one that serves as a master and supporting slave nodes. All nodes including sensors are controlled from one operating system. Because Android Things is a fork of the popular Android operating system that is used in various devices around the world today, its API does not differ much from that of the mobile application development and every sensor is an object level abstraction in the system. The compact nature of this solution means the development and deployment time is significantly cut down. Android Things is naturally the choice for use on the proposed remote sensor network. Figure 6 below lists the Google Android Framework and API which is also the Android Things Framework and API.

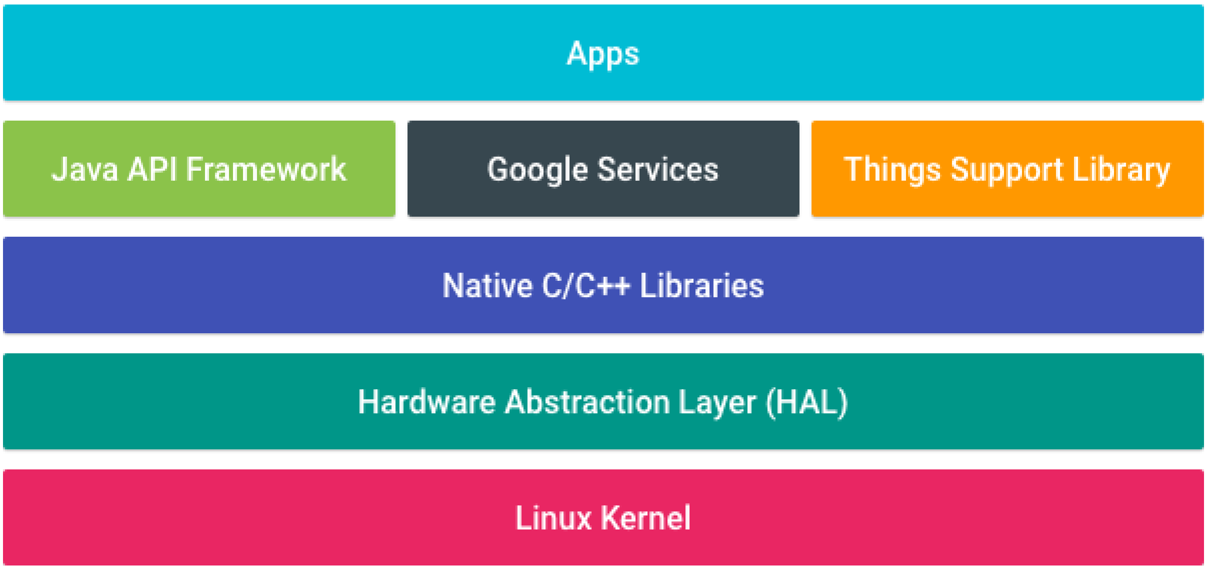

Figure 6- Android Things Framework and API(Google 2016)

As of early 2017, about 4 devices from different manufacturers around the world supported the Android Things operating system which was in its beta release or early public testing release. Some of the devices included the Intel Edison, Intel Joule and the Raspberry Pi 3. The Android Things operating system is then installed onto the selected hardware platform, with respect to this work, that platform was the

Raspberry Pi 3 model B. The mode of programming applications for the operating system does not differ much from that used during development of applications for mobile phones and tablets.

While there are similarities in the framework and API to that of Google's Android, the development methods differ slightly and these are discussed. The Google API for Android is extended by Android Things which adds additional API's in the Things Support Library. The library is used to enable the integration of hardware devices that are not normally found on mobile phones and tablets such as smoke detectors. It is also important to note that the Android Things operating system does not come with any app installed. The first app to be deployed on the platform is the app being developed and this app is optimized to start-up as soon as the device is booted. This solves one major issue which is the use of system resources in remote sensor networks. It is important to make the remote sensors as lean as possible in order to conserve battery life and processing ability. Below we take a look at the important features built into the Android Things operating system.

2.2.16.1. Things Support Library

The Android Things Support Library is composed of the Peripheral Input/output (I/O) application programming interface (API) and the User Driver API. The Things Support Library is an addition to the traditional Android operating system for mobile with the inclusion of features that are specific to sensors and protocols built specifically for sensor networks. We discuss each of the API in detail below;

2.2.16.1.1. Peripheral I/O API

The application programming interface for input/output device support many different types of interfaces. In the context of computer programming and according to the encyclopaedia Britannica(Hosch 2019f), an application programming interface, API is a set of standardized requests that enable computer programs to communicate with each other. In this case, the computer program is viewed as a closed system whose internal workings are unknown, but the API makes it possible to use the services purported to be offered by that program. In this case, the hardware peripherals perform certain operations such as a humidity detector detecting humidity. We do not know how that humidity detector works probably due to its proprietary nature but what we know are the commands that would enable us to read the humidity or set certain thresholds for the trigger of an event from the sensor.

The peripheral I/O API supports the following standardized interfaces; general purpose input/output (GPIO), pulse with modulation (PWM), inter-integrated circuit (I2C), serial peripheral interface (SPI), universal asynchronous receiver/transmitter (UART), native peripheral input/out (PIO) and inter-IC sound (I2S).

2.2.16.1.1.1. General Purpose Input/Output (GPIO)

The GPIO interface is used to control simple binary input such as that of an on/off button. GPIO provides a programmable interface which is usually a pin that can be programmed to be either an output pin or an input pin.

2.2.16.1.1.2. Pulse with Modulation (PWM)

Pulse with modulation is a digital interface that is used to control devices with proportional states. Examples of the use cases of PWM are in the control of the brightness on an LED display.

2.2.16.1.1.3. Inter-Integrated Circuit (I2C)

I2C is an interface that is used to connect devices that send simple payloads to each other. It is a serial interface with one device acting as a master and providing the common clock signal required in serialized communication. In I2C interfaces the clock, ground and bus are shared. This might be akin to the central processing unit, memory unit and storage unit in a computer which are all managed by the CPU and share the same system bus.

2.2.16.1.1.4. Serial Peripheral Interface (SPI)

The serial peripheral interface works just as the I2C interface does with the distinction that the SPI supports high bandwidth use cases. SPI supports full duplex communication which means that a device can both send and receive data at the same time.

2.2.16.1.1.5. Universal Asynchronous Receiver/Transmitter

The UART interface is used for the interconnection of devices that send raw data. This means that both the byte format and data transfer speed are configurable. The common term for the UART interface is the serial port. As its name suggests, UART uses asynchronous communication as there is no clock to guide the data transmission/reception intervals between devices. The timing intervals will have to be negotiated by both devices and this is usually achieved programmatically. UART supports full duplex communication but is restricted to only two devices per UART connection.

2.2.16.1.1.6. Native Peripheral Input/Output (PIO)

The native PIO allows an extension of the Android Things library by writing code to communicate with peripheral devices using native C/C++ which are common programming languages for embedded devices.

2.2.16.1.1.7. Inter-Integrated Circuit (IC) Sound (I2S)

The I2S interface is a bus that connects devices that support the pulse code modulation sound encoding system. This is usually used to connect devices that output PCM data to each other.

2.2.16.1.2. User Space Driver API

User driver space API’s allow developers to extend the Android Things framework with custom interfaces that allow device specific API to be recognised by the frameworks. Figure 7 below is snapshot from the Android Things website.

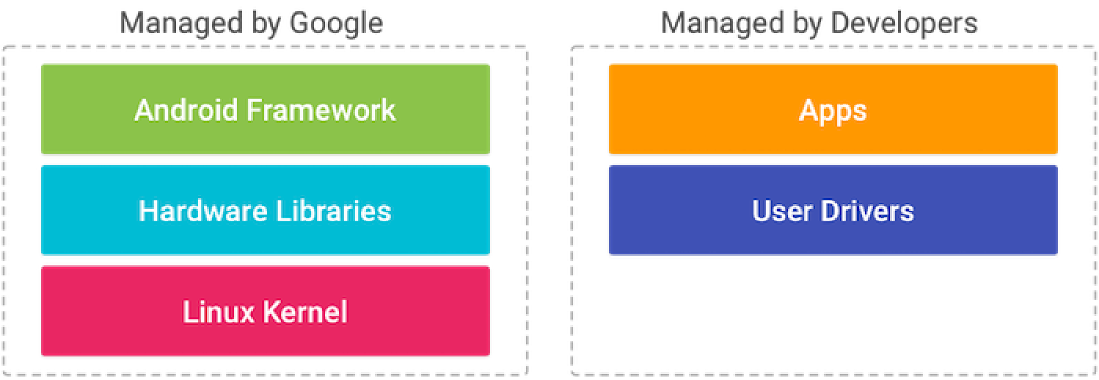

Figure 7 – Android Framework and User Drivers (Google 2018)

It can be seen that any type of sensor that is created only required code in the user space drivers specific to that sensor. Nothing changes as concerns the overall implementation of the Google framework. This means that standard system calls can be used by Android things in order to communicate with the custom sensor using custom drivers. This makes Android Things an extremely extensible framework.

2.2.17. Sensors

Sensors are an important part of the IoT architecture and sensor networks as a whole. They form the layer that monitors some physical characteristic of the environment. A sensor should have three basic attributes, sense the surroundings, relay the information, and have some form of communications medium. The sensor is a modular part of the sensor network architecture and should be easily upgraded while the underlying communications interface remains the same. This makes it possible for say the improvement in the sensing mode or algorithm without necessary having to change the device to which the sensor communicates its data to. The data coming from a sensor may be raw or encoded. In the case of raw data, the user may have to be able to write low level code that acts as the driver and interprets the sensors output into higher level machine readable instructions sets for further interpretation. For the purposes of this thesis, we discuss each of the sensors that were used in order to build the proof of concept for the sensor network.

2.2.17.1.1. Temperature and Humidity Sensors

There are various types of temperature and humidity sensors in use for various types of applications. The type of ambience sensor chosen is due to the characteristics of the environment to which it will be deployed. For example, one would expect a completely different type of sensor to de deployed in a metal smelting factory as compared to a grain storage warehouse. The physical characteristics and mode of workings of the sensors would differ. In the case of sensors for grain management, two types of sensors were considered, the DHT22 indicated in Figure 8 below and the BME280 integrated sensor from Bosch indicated in Figure 9 below. General characteristics of the two sensors are indicated below;

- They are relatively cheap
- They are digital hence easy to interface
- They have low power requirements
- The temperature and humidity range are suitable for agricultural applications

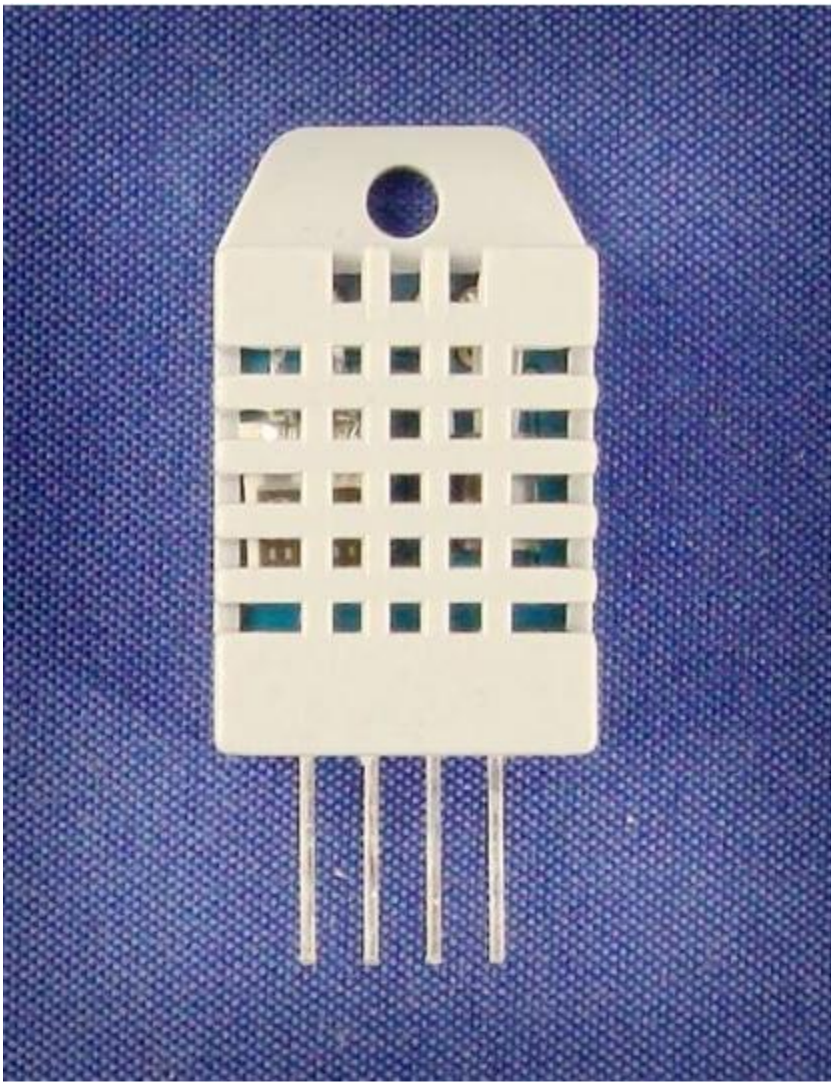

Figure 8- DHT22 Temperature and Humidity Sensor

Table below show the technical specifications of the DHT22 sensor.

Table 1 - DHT22 technical specification

Model	DHT22
Power supply	3.3-6V DC
Output signal	digital signal via single-bus
Sensing element	Polymer capacitor
Operating range	humidity 0-100%RH; temperature -40~80Celsius
Accuracy	humidity +-2%RH(Max +-5%RH); temperature <+-0.5Celsius
Resolution or sensitivity	humidity 0.1%RH; temperature 0.1Celsius
Repeatability	humidity +-1%RH; temperature +-0.2Celsius
Humidity hysteresis	+-0.3%RH
Long-term Stability	+-0.5%RH/year
Sensing period	Average: 2s
Interchangeability	fully interchangeable
Dimensions	small size 14*18*5.5mm; big size 22*28*5mm

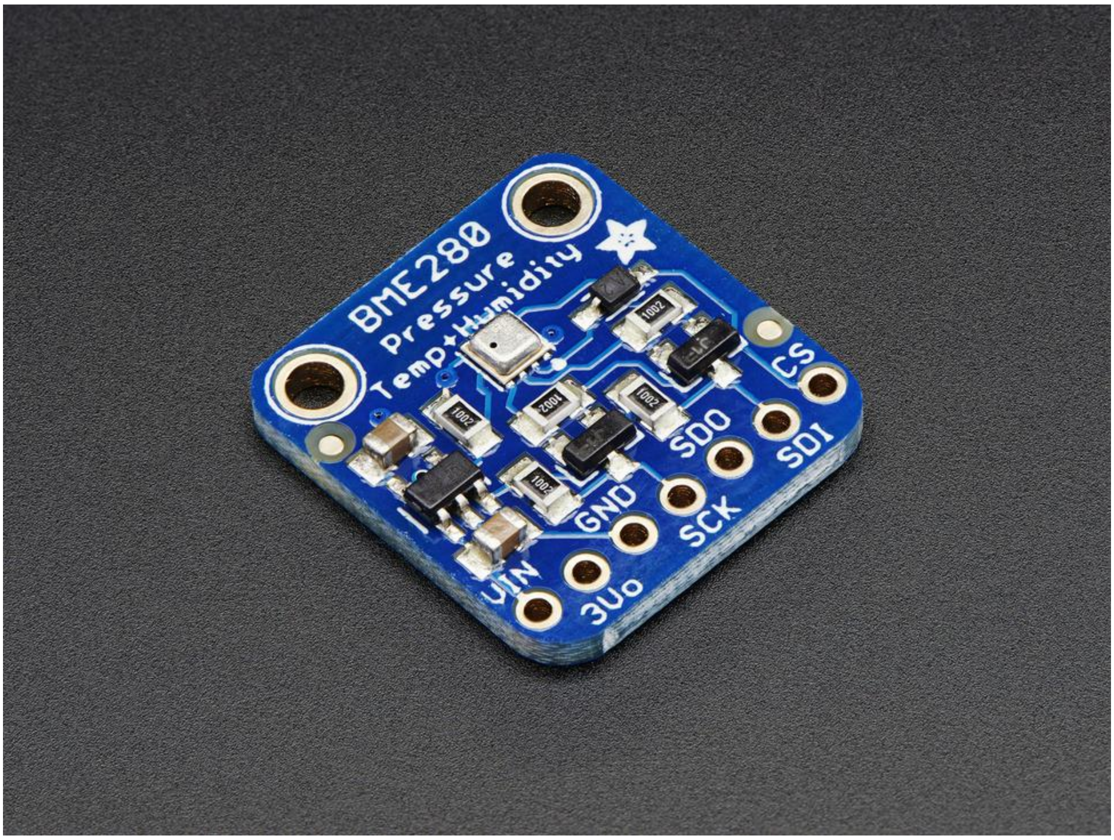

Figure 9 - BME280 Integrated Temperature, Humidity and Pressure Sensor

Table 2 below shows the general electrical technical specifications of the BME280 integrated temperature, humidity and pressure sensor.

Table 2 - Technical specifications of BME280 Integrated Sensor

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Supply Voltage Internal Domains	V_{DD}	ripple max. 50 mVpp	1.71	1.8	3.6	V
Supply Voltage I/O Domain	V_{DDIO}		1.2	1.8	3.6	V
Sleep current	I_{DDSL}			0.1	0.3	μA
Standby current (inactive period of normal mode)	I_{DDSB}			0.2	0.5	μA
Current during humidity measurement	I_{DDH}	Max value at 85 °C		340		μA
Current during pressure measurement	I_{DDP}	Max value at -40 °C		714		μA
Current during temperature measurement	I_{DDT}	Max value at 85 °C		350		μA
Start-up time	$t_{startup}$	Time to first communication after both V_{DD} > 1.58 V and V_{DDIO} > 0.65 V			2	ms
Power supply rejection ratio (DC)	PSRR	full V_{DD} range			±0.01 ±5	%RH/V Pa/V
Standby time accuracy	$\Delta t_{standby}$			±5	±25	%

There were obvious advantages of the BME280 sensor over the DHT22 sensor. For example, the BME280 sensor was natively supported by existing user space drivers on the chosen Android Things operating system while drivers were required to be defined and coded for the DHT22 sensor. Also, the BME280 sensor contains three integrated sensors accessible via similar application programming interface calls which simplifies the code. However, since a framework was created for the use of generic sensors, it does not really matter which sensor is selected in the end and all can be accessed using our models high level interface calls as described later in chapter 4.

2.2.18. Business Process Modelling Notation (BPMN)

We now take a look at a fundamental aspect of our research and this is the mapping of the FRA business processes using a standard. In this section, we explore the BPMN version 2 standard that will be used in the results section. Business process modelling notation BPMN is an international standards organisation standard and

International Electrotechnical Committee standard(ISO/IEC 19510:2013)(2013g) for the formulation and mapping of organization business processes. Its aim is to provide a format and notation that is widely acceptable amongst the vast majority of users across all industries for a standardized way of showing business processes. It bridges the gap between systems analysts, technical developers and end users. With this standard, changes to business processes are easily incorporated and a system can be designed in a modular and easy to understand framework. Also, once business processes are laid down in a standard format, it may also be determined that there may be no need for system development from scratch as the business process mappings may be compared to existing platforms that may be easily customised and made to work for the specific requirements being sought. BPMN V2 of 2013 uses graphical illustrations to communicate the business processes being defined. The advantage of BPMN is that business processes are defined and can be automated. In Table 3 below, we define examples of some of the business process objects that have been used in order to map the FRA business processes. For the others, refer to the appendix A.

Table 3 - Business Process Mapping Notation sample object reference

Object	Name	Description
	Business rule	This is an object that defines a task that depends on input from business rules or regulations. This can normally be implemented or automated by a business rules engine
	Parallel gateway	Indicates that parallel activities or tasks may be performed where used. The activity or task being defined by the association or flow

	Receive	Indicates that something is being received

2.2.19. Products and Platforms – Solution Extensibility

As we build a solution for FRA, we want it to have a long lifespan and to possibility have applications beyond that one organization. Hence through research, we noted that it is important to look at the solution as a platform and not a product only. With respect to sensor networks, a product is defined as a tool that is used in order to build the sensor network. Various products may be used in order to achieve the goal ranging from hardware products to software products. Each of these products may have a different method of operation or rely on different software and hardware in order to get them working. For example, a wireless sensor network may be composed of a Raspberry Pi, an Arduino, a mosquito server and some communication network. Below we define which of these products are platforms. The broad definition of a platform is that it serves multiple groups or products or users and facilitates interactions between them. The users may be human, machines or software and each of them may be distinct, requiring individual functionality but at the same time may require exchange of data. With that broad definition, we list the hardware, software and other components used in a sensor network and define whether they are platforms or products by asking the following questions;

1. Does it serve multiple users or customers?
2. Does it facilitate interaction between users?

We discuss each of the questions below in order to show the context in which we had them applied to the questions of whether an item is a product of a platform. Let us consider a practical example such as Airbnb(Zekanovic-Korona & Grzunov 2014). On the question of whether it serves multiple users, the answer is yes because it is a platform at which anybody that does not own it or does not need to know its technical workings may use its services. It also facilitates the interaction between multiple users because it brings together buyers and sellers who can then interact by exchanging goods or services for money. When we look at the current model used in building sensor networks, we list the most common devices and applications and apply those two important questions to each of them. We also applied those questions to our selected environment, Android Things. Our conclusions are indicated in Table 4 below.

Table 4 - Products and platforms of selected technologies

Determine whether component is a product or a platform	**Major components of our wireless sensor network**			
	Mosquitto Broker	***Raspberry Pi***	***Arduino***	***Android Things***
Does it serve multiple users	Y	Y	N	Y
Does it facilitate interaction between users	Y	Y	N	Y

Android things is our selected software for the development of the Food Reserve Agency's remote sensor network because it is a platform and the following benefits will be realized if a platform is used as opposed to a product or multiple products;

2.2.24.1. Reduced Technical Overhead

Platforms offer reduced technical overhead because they form a base layer that facilitates interaction between several parties without the unnecessary technical complexity such as the need for specific programming languages and development environments for each component within a system. An example for the sensor network is that one programming language may be used to communicate with all peripherals and the aggregator.

2.2.24.2. Scalability

Platforms can easily scale to support new features by simply designing them to be modular such as the case is in most operating systems. This way, new peripherals, sensors and devices could easily be supported by third parties because the platform by its definition serves the needs of multiple users hence we assume that for it to be a true platform, it must support extensibility and scalability third parties through access to the platform specific application programming interface.

2.2.20. Related Works

Significant research has been done into wireless sensor networks as applied to grain storage(Vinay Sambhaji Suryawanshi & Mahesh S. Kumbhar 2014) and general warehousing environment monitoring(Wang Qin Chen Zhonghui Chen Xin 2009) to systems that employ these networks for automatic irrigation(Purnima, S.R.N & Reddy, PhD 2012). In South Africa, e-governance was introduced in order to make public services more efficient and this included services related to agriculture while in Kenya, e-government was introduced in order to deliver service quicker to the public and this also included agricultural services.(Namisiko & Aballo 2013)(Maumbe & Okello 2010). What we aim is to introduce such technology to the Zambian agricultural sector by targeting one of the biggest grain market players, the Food Reserve Agency.

In the context of Zambia, we will make use of existing public wireless networks for relaying information from remote locations and personal area networks or wireless local area networks based on either Zigbee or Wi-Fi at remote locations to rely information locally. We will also make use of the available fiber infrastructure from telecom providers as backbone networks in order to provide redundancy and possibly host databases over multiple sparse geographic locations.

2.2.20.1.1. SCADA Networks

SCADA is an acronym for Supervisory Control and Data Acquisition. SCADA used in industry to control critical components in automated networks, SCADA systems do not generally control processes in real time and provide critical data which is used to mitigate downtime and manage efficiency in industrial processes. SCADA systems are composed of the following components;

- Human Machine Interface (HMI)
- Programmable Logic Controller (PLC)
- Remote Terminal Unit (RTU)
- Communications infrastructure
- Supervisory system

The human machine interface is the interface at which data about the system is presented to the user for decision making purposes or further interventions or for information purposes only. The programmable logic controllers make decisions that initiate, stop or continue specified processes. The remote terminal units are the actual devices performing a process. The communications infrastructure is the network that the SCADA system uses to communicate within the ecosystem.

The setting of a SCADA system is somewhat similar to that of remote sensor networks with a few exceptions namely;

- SCADA systems control industrial processes. There must be a process and the data that is generated from sensors within a SCADA system is used by remote controllers to automatically manage that process.

2.2.20.1.2. ICT in Water Management

Water management can be closely linked to strategic food reserve and as such it is important to look at the role that ICT's play in water management. Access to clean water for all is one of the key targets in the United Nations 2030 Sustainable Development Goals (SDGs). Several economic sectors such as the energy and agriculture sectors rely on water for effective operation. In Zambia for instance, hydro power is the major electrical energy source accounting for 83% of Zambia's installed electric capacity(Energy Regulation Board - Zambia no date); the agriculture sector is also highly dependent on irrigation systems for food production (Government of Zambia 2006). Correspondingly, energy is needed for provision of water as well as for food production. It can therefore categorically be stated that a delicate link exists between water, energy and food production and for that reason it is vital that appropriate measures are implemented to make certain of continued availability and provision of water. ICT's have been successfully used in water management solutions and the principals can also be applied to the managements of strategic food reserve.

2.2.20.1.3. Internet of Things for Smart Water

The activities associated with detecting water levels, leakages, determining water consumption, water pressure and where water is being wasted for an overall effective optimisation of water usage and conservation of the water resource in many parts of the world is already accomplished through the concept of Internet of Things (IoT) applications. IoT embodies the interconnectivity of physical and digital tools and devices such as smart meters, sensors, controllers and alarms to mention a few and the global information and communication infrastructure. An interconnectivity of these tools and devices in the water sector creates a system that enables real-time monitoring and oversight of the water systems to facilitate for prompt repairs and provision of information for decision making that allows for the efficient performance and operation of the water systems. An example is sensors placed in water tanks to detect water levels and leakages and through IoT applications relay this information to IoT devices such as tablets, phones and laptops to mention a few that allow for tanks to be refilled remotely when the water levels run too low and to prompt for patching up of any leakages. IoT as define by the International Telecommunications Union (ITU) is a global infrastructure for the information society enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable ICTs. One of the promises of the Internet of Things (IoT) is that everything should to each other. These talkative "things" include sensors, consumer appliances and smart meters among others which are able to be integrated on the network. These "things" generate associated information that is fundamental in performing data analytics for better decision making. It is clear that IoT applications are increasingly becoming paramount to the successful execution of water management strategies aimed at alleviating the water crisis. Among the promises of IoT for water management are:

i. Smarter collection and measurement of water informatics such water quality and pressure
ii. Better communication making information gathering and analysis easier
iii. Water leakage detection which help to improve the management of the water distribution network
iv. Transparency in water consumption which contributes to improved revenue realisation and
v. Improved efficiency in water use.

IoT systems are also be applied in protecting water related ecosystems such as energy, agriculture and forests which affect water sustainability as well as energy consumption and food production. IoT is therefore well suited in creating a centralised network with sectors that are closely linked to the effective management of the water systems and in establishing synergies that ensure effective and efficient cooperation among these sectors. Figure 10 depicts the important role that IoT plays.

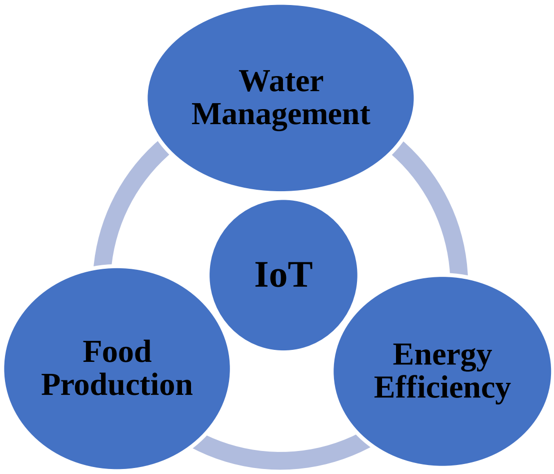

Figure 10- IoT and Water, Energy and Food Nexus

Technologies such as satellite remote sensing in combination with semantic sensor web and geographical information systems are used innovatively by water authorities in developed countries to obtain information in real time about water use, to track and forecast the level of rivers and to identify new sources of fresh water. With the impact of climate change, sole reliance on historical hydrologic weather patterns is no longer a viable forecast for water authorities. The availability of information about current conditions in a particular situation on a timely basis is crucial for decision making in water resource management (ITU-T Technology Watch Report 2010). ICTs present a unique opportunity to generate data on the dynamics of the water supply and distribution network and enable remote analysis of and provide information on the water environment such as water pressure, leakages, water use and water levels. ICTs can also be applied in making available other related information that affect the availability and use of water such as soil moisture, temperature, wind and detection of new water sources to mention a few; all of which are vital in forecasting, decision making, controlling usage and efficient and effective water management. The very models that have worked well for water management solutions are applied to the remote sensor network discussed in this thesis.

CHAPTER THREE
METHODOLOGY

3.1. Introduction

In this section we look at the materials and methods used in order to construct the research. We first look at the baseline study that was conducted in order to determine the significance and viability of the research and then we delve into the various optimization recommendations that we designed and models that we built before going into the developed prototype for the remote sensor network and platform recommendations. We also used requirements specifications for our solution which we obtained from the business process reengineering method using the business process modelling notion version 2 standard. At the beginning of the research, we set out by asking 4 main questions and relating these to technical objectives and proposed methodologies. Table 5 is a summary of our setup.

Table 5 - Summary of Research Questions, Objectives and Methodology

Research Question	**Technical Objective**	**Methodology**
What are some of the challenges faced by FRA through the usage of the manual system for the grain marketing and grain storage?	To conduct a baseline study in order to establish the challenges faced by the manual system of grain marketing, grain storage at FRA.	Interviews, interaction with FRA and FISP staff at Lusaka, Mumbwa and Chongwe offices. Questionnaires may also be used.
Is it possible to map the current business processes of FRA and develop a model using the cloud architecture and wireless sensor networks in order to address the challenges in (1)?	To map the FRA grain marketing and storage business processes and build a model using cloud infrastructure.	Review several available methods of storing data captured from sensors, determine what time intervals are appropriate if polling will be used.
How can we develop a database with a web portal and mobile interface using the model in (2)?	To develop a database with a web portal and mobile interface using the model in (2).	Analyse available technologies in Zambia and abroad, list the pros and cons of each available medium and select the most appropriate that is suitable to the requirements of the food reserve agency database, web portal and mobile application.
To what extent can we develop a remote sensor network for sensing temperature and humidity using the model in (2)?	What kind of technology can be used to develop a remote sensor network for FRA?	Research on modern warehouses to determine what methods are used to manage security and the environment and try to devise a solution similar that is applicable to Zambia.

3.2. Baseline Study

A baseline study was conducted in order to determine the real challenges from the end users about the day to day operations of the Food Reserve Agency. The baseline study involved a mixed methods research, interviews and purposive sampling and visitations of FRA warehouses. A mixed methods research was used as it was determined that using quantitative data alone may not necessarily give a true picture as to the challenges faced as documentation is clearly a weak point in the day to running of the affairs of the food reserve agency. We also employed the use of qualitative methods such as interviews and observations at some of the busiest warehouses at Mungwi Road, Mumbwa and Chongwe. The Mungwi Road warehouse was the largest central depot for the entire Lusaka Province and the Mumbwa warehouse was the largest depot for the entire central province. Key personnel were determined and asked to give a detailed overview as the manual business processes being employed.

3.2.1. Sampling, Analysis and Inclusion Criteria

150 questionnaires were prepared and distributed to four purposively selected FRA warehouse at Chongwe, Lusaka West, Mungwi and Mumbwa. While FRA has several warehouses spread throughout the country, the structure of its operations is such that smaller warehouses are only responsible for the collection and temporal storage of grain before it is forwarded to main deport within a predefined zone or district and then to a central warehouse. Most of the satellite depots have seasonal staff whose main role is mostly to collect and record grain in standard FRA bags. They are also responsible for stacking of the grain. The data that is manually recorded is forwarded to central warehouses where more technical analysis is done with the use of Microsoft Excel Worksheets. Table 6 shows a sample of an FRA stock report for the grain maize recoded in Microsoft Excel.

Table 6 - Sample of FRA stock report in Microsoft Excel

FOOD RESERVE AGENCY

WHITE MAIZE STOCK PER YEAR REPORT
As at 09.12.2015

No	Region	District	Location	STOCK POSITION BY YEAR				Total Stock (bags)	Good maize
				2012 (bags)	2013 (bags)	2014 (bags)	2015 (bags)		
46	Lusaka	Chongwe	Main Depot			-	33,670	33,670	33,670
47	Lusaka	Itezhi Tezhi	Main Depot				17,867	17,867	17,867
48	Lusaka	Kafue	Main Depot	7,165	-	7,443	362,995	377,603	377,479
49	Lusaka	Lusaka	Mwembeshi Main Depot	13,171	-	3,264,768	1,327,370	4,605,309	4,605,284
	Lusaka	Lusaka	Mungwi Main Depot	65,411	-	1,990,762	684,225	2,740,398	2,740,368
50	Lusaka	Mamvule	Mamvule Main			-	4,623	4,623	4,623
51	Lusaka	Mumbwa	Main Depot		-	-	95,747	95,747	95,747
54	Lusaka	Rufunsa	Main Depot			8	1,272	1,280	1,280
55	Lusaka	Siavonga	Malengo				2,000	2,000	2,000
Sub total				**85,747**	-	**5,262,981**	**2,529,769**	**7,878,497**	**7,878,318**
Grand total				**85,747**	-	**5,262,981**	**2,529,769**	**7,878,497**	**7,878,318**

The determined processes and procedures entailed that studying a few purposively selected warehouse locations would give a very good overview of the general business processes at all other warehouses. The questionnaires mostly consisted of closed ended questions relating to the use of ICT's in grain storage and grain warehouses. The aim was to find out from the FRA staff whether ICT's played a key role in the business processes of the organization.

We also conducted face to face interviews with key management staff such as the depot clerks who are individuals in charge of a specific depot that belongs to a specific warehouse; the store shed managers who have under their management other members of staff such as general workers. We also toured three of the four facilities in order to get hands on experience as the physical handling of grain and the everyday processes followed by the FRA staff from the security to the business development manager. Data was collected between October and December 2016.

3.2.2. Collected Data and FRA Business Rules

A lot of forms and electronic documents were collected and these were invaluable to determining the FRA business rules which later fed into our business process mapping to be discussed later. Several of the documents can be seen in appendix B.

3.2.3. Data Analysis and Data Processing

In order to process and analyse the data, we used Google Forms which made it easy for us to collect the data from the paper-based forms and also include electronic forms that were used during the face to face interviews. The face to face interviews included the same questions that we had in the self-administered questionnaires. Google Forms also made it easy to export he data in standard formats such as the Comma Separated Value format for easy importation into other software packages should further research be required. Google Forms also has predefined visual representation of data such as Pi Charts, Bar Graphs and Scatter Plots, these were also used in order to analyse the data.

3.3. Business Process Mapping

The current business processes for the Food Reserve Agency were mapped out by Cynthia Muyunda in her thesis where her main aim was to employ the use of radio frequency identification or RFID and design a model for a grain inventory management system(Muyunda 2016). The current business processes may be seen in Figure 11. She does mention a Zigbee wireless sensor network as part of the proposed business processes, but this was never discussed in detail and never actually designed and realised. In this work we complete that design and further extend the work with business processes for the organization mapped out using the business process modelling notation version 2 standard which can be seen in Figure 12. This standard enabled us to graphically illustrate the business processes and easily identify where automation could add benefits to the organization with several other benefits previously discussed in chapter 2 under the sub heading "Business Process Modelling Notation". Also, in the current business processes it has been noted that the entry point of the grain at satellite depots was not captured. Through our self-administered questionnaires and interviews, we were able to map the processes related to how grain is first collected from suppliers in the field and to what level of food traceability FRA operates.

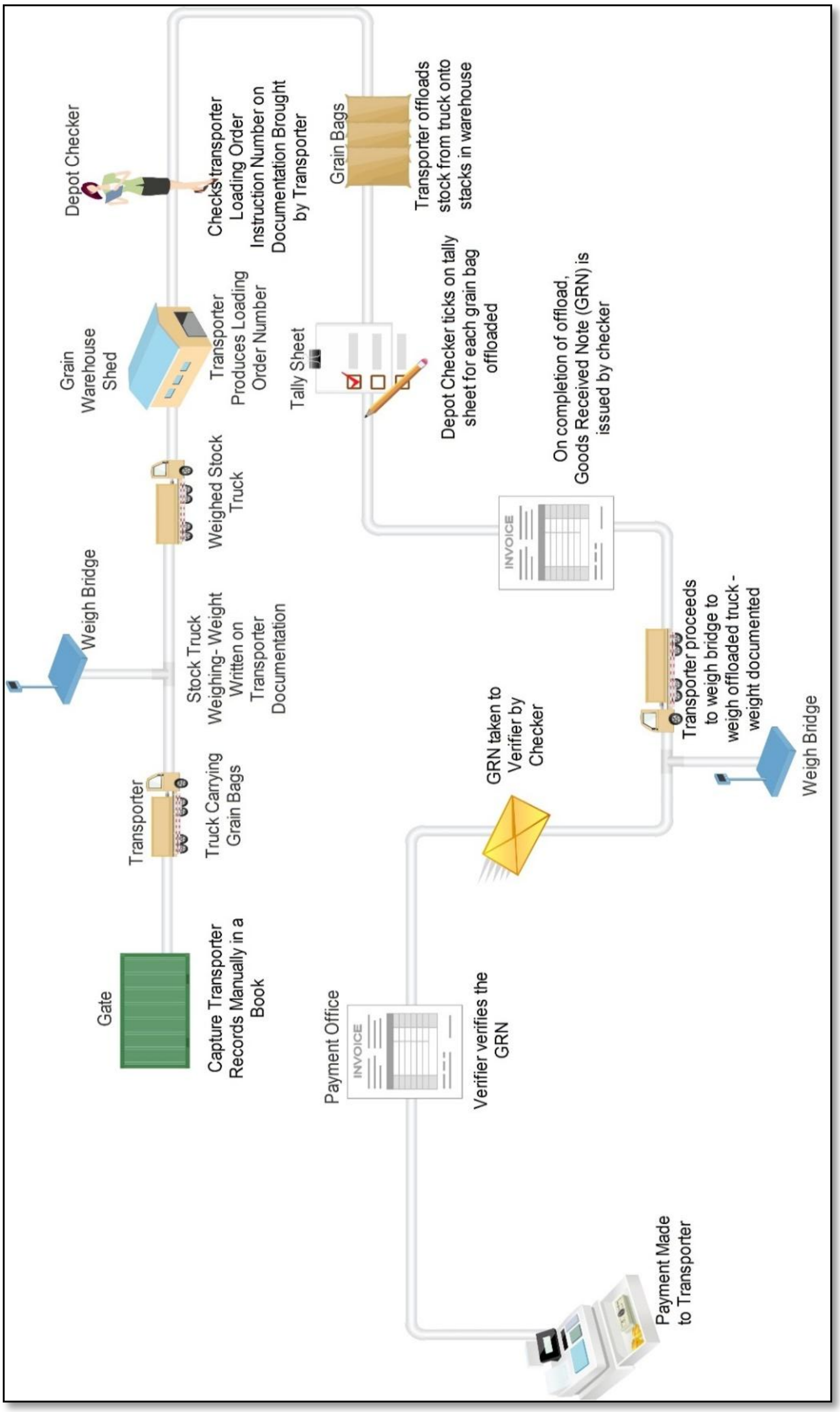

Figure 11- Current FRA business processes by Cynthia Muyunda (Muyunda 2016)

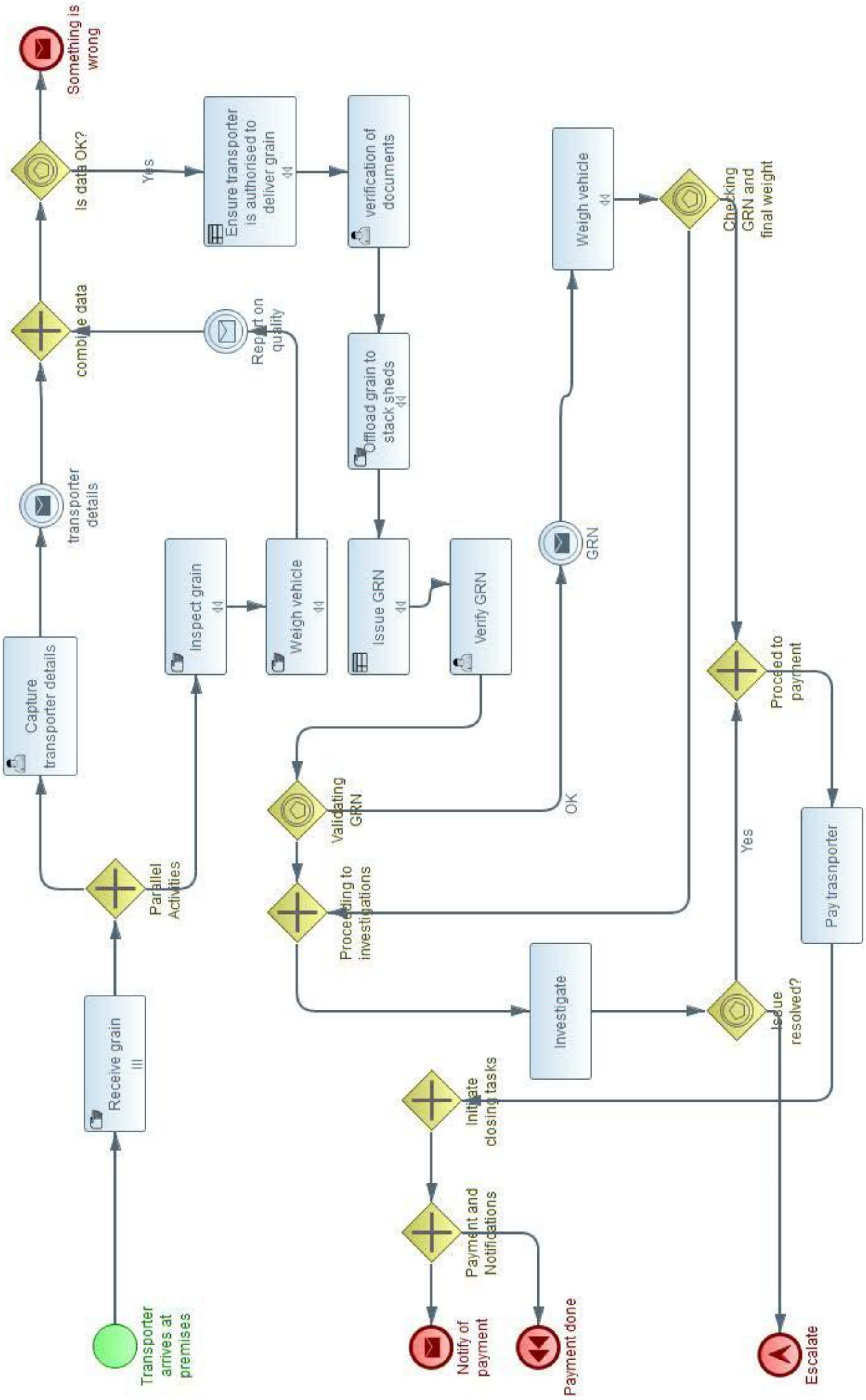

Figure 12 -Current grain collection business process in BPMN 2.0

From the above business process, we can see the workflow of the grain collection at a central or main depot which was our selected area of study. It must be noted that all the processes are currently manual. For the purpose of this research, we are interested in capturing the data produced by the business rules and the inventory collected after that. The business rules produce the following information;

- Grain type
- Grain quantity
- Grade(quality)
- Farmer name
- Supplier name
- Supplier residence
- Supplier compensation information

The information indicated above was identified as required but unfortunately, this data is not currently captured due to obvious manual handling. Below each of the items in the business process model are discussed in detail.

3.3.1. The Start Phase

The FRA business processes begin when a farmer arrives at FRA and is interested in selling grain. This is indicated by the start circle in BPMN. FRA does not gather farmer or supplier data. The only indication as to from whom stock was purchased may come from a receipt indicating that FRA has received crops and paid money to a supplier. Before FRA pays money to the supplier, the grain is inspected and graded. This information is however not very useful as in subsequent years, FRA may not have the data required in order to analyse supplier quality based on past receipts. This potentially brings about the danger of food traceability. The purchased grain is then placed at a storage shed within the confines of the designated FRA warehouse.

3.3.2. Collection of Grain in the field

The food reserve agency does not discriminate as to whom it collects grain from in the field. The collection of grain is seasonal, and it was our intention to map-out the entire process from the field to the time that grain arrives at the central warehouses.

3.3.3. Receiving Grain at a Camp, Shed or Depot

At all FRA camps, sheds or depots, grain is first received into the perimeter of the facility using personal transportation is the case of smaller warehouses such as camps and sheds but pre-authorised transporters in the case of all major depots.

3.3.4. Inspecting Grain

FRA grain that is first received from the receiving stage is subjected to random checks in order to assess its grade or quality based on internal FRA standards. A sample dipstick is used to randomly pick a few of the crop sample and visual analysis is done in order to rate the received grain. Rating grain this way has the advantage of FRA being able to offer premiums for superior grain that can also be used for export purposes.

3.3.5. Weighing and Packing Grain

After the grain has been inspected, it is bagged and tagged with the information indicated below;

- Grain name
- Year received
- Grade
- Shed No.
- Stack No.

That way, FRA is able to manually track and trace the grain. We suggest here that added information such as the source of the grain needs to be specified in order to improve upon food traceability. This can be more efficiently handled if packaging and grading is done at source instead of aggregating grain before mass transporting to main depot locations.

3.3.6. Stacking Grain in Warehouses

After the grain is bagged and tagged, it is then stacked in the target shed for storage until a purchase is made from FRA. During the 2016 visit, FRA had grain that had been stored as early as 2012. Sheds are to be kept at just the right environmental conditions so that grain is not spoiled. Standards for keeping grain are suggested by the Food and Agricultural Organization (FAO) and this can be seen in Appendix E.

3.3.7. Compensating Suppliers

Compensation happens when the transporter complies with all the business rules. At the same time the transporter is paid, a notification of payment is sent to the transporter and the internal FRA accounting department. The transporter then leaves the premises after the vehicle is once again weighed and compared with the GRN. A simple computation is done to indicate that the reduced weight of the vehicle should be equal to the offloaded weight as indicated on the GRN or else something is wrong and a signal is thrown to that effect.

3.4. Database Development

For the database design we used entity relationship diagrams following the unified modelling language standard after examining the requirements specification. We developed the database using the MySQL database engine. The database was normalized up to the third normal form or 3NF. Use case diagrams were also used in order to show the objectives of the system that lead to the specific database tables being designed in order to capture the relevant data connected to various business processes. Below we discuss some attributes of the database.

3.4.1. FRA Database Design

The unified modelling language is a standardised method of abstracting and modelling in software development. The unified modelling language can therefore be used for the system and process modelling at FRA. Entity relationship diagrams which are loosely based on UML were used for data modelling and database modelling. In database design, it is important to look for the relationship between the different processes in an organization and how those processes generate data and output that data to other processes. Because UML provides object-oriented methods towards the design approach, it is a good option for abstracting an organization as a body and defining the working relationships between the different body components. An organization can be thought of as a body consisting of members and those members each have a specific function to perform. If the body wanted to achieve a specified goal, the individual processes that lead to that goal are activated by each of the respective body members. In essence, every department within an organization is somehow linked to another department within the same organization. It is the job of database design to find out what those relationships are and create a data and process model for the organization. The FRA database was designed by carefully conducting interviews and reviewing all the documentation that is used in their everyday business operations. A careful examination of the forms was then abstracted into data models and eventually into a database model using the relational database approach. The relational database model was chosen because of the following reasons;

- The relational database model ensures accuracy by enforcing entity relationships. This means that data can be referenced by a special field called a primary key which is unique for all the data in a specific entity or table. It was discovered that FRA uses unique document identifiers for the various forms that they have hence the uniqueness of the relational database approach best suited the form definition into a data model.
- The relational database model is the most widely used and trusted model today. The relational model has stood the taste of time and support for the implementation in this approach may not be a problem. There also exist various open source database management systems which support the relational database model architecture.

Other forms of database models include the flat model which is basically a plain file with no indexing capabilities. Flat files were also commonly used by FRA. An example of how a flat file is updated is when a user opens an Excel document that is used to keep track of sales during a month. The file will have to opened in its entirety, updated and finally closed. In the age of unstructured big data, another common database model is the object-oriented database model. The object-oriented database model uses a hybrid approach by combing a relational database with object-oriented programming. This means that a user can use a native programming language in collaboration with a standard database definition and database manipulation language in to define, manage and process data. Below is a description of the 26 tables that were designed after analysing the FRA data requirements and business processes from interviews and business forms. The tables are grouped into a logical manner so that a collection of them are discussed as whole. The logical grouping helps in understanding the specific goal and requirements of having the tables. Where there is no need for a logical grouping, an individual table is discussed in detail.

3.4.1.1. The Transporter

Figure 13 below list the ER diagram for the transporter use cases. The transporter is an actor in the FRA business processes. The transporter ferries good from the FRA satellite depot to the main depot or between depots. The transporter in this case is a company or sole trader that is represented by a driver. This means that a transporter can have multiple drivers and if those multiple drivers can drive different vehicles, then the transporter can also have multiple vehicles. The transporter has certain attributes which can be addressed by considering the system requirement in the use case diagram shown in Figure 13. All transporters are pre-registered by FRA hence their details need to be captured. The next part is to determine what those details are. The tables below show what specific transporter data is required by FRA.

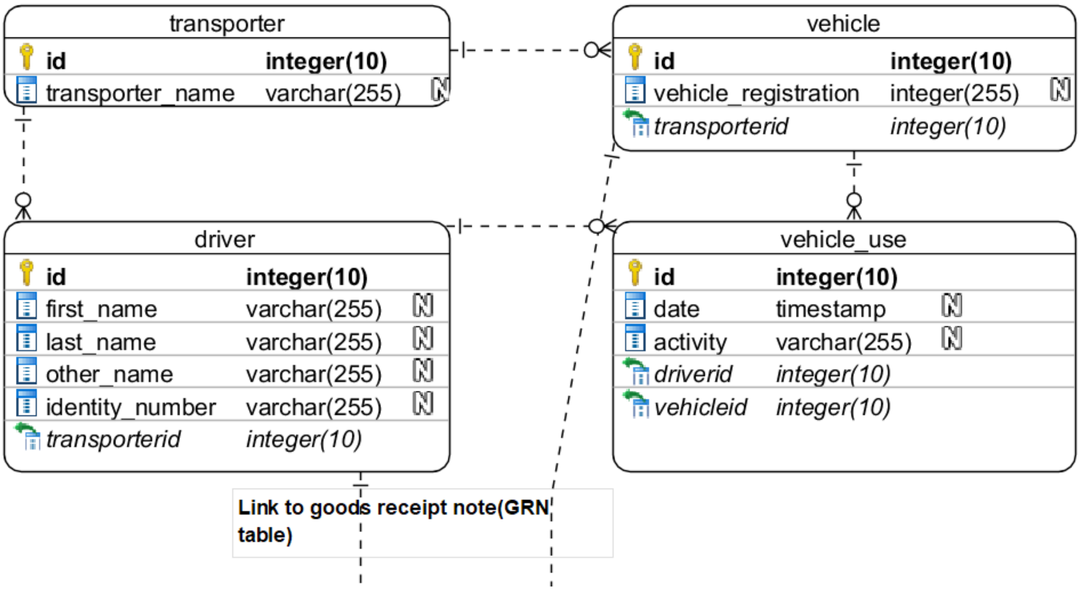

Figure 13 - Transporter, driver and vehicle entity relationships

The tuples have intuitive naming conventions so that they offer self-explanatory attributes. It is clearly visible from the above entity relationship diagram that a transporter can have multiple drivers and multiple vehicles. Designing the database tables this way can enable FRA to easily identify the transporter from their drivers or their vehicles. Another important story told by Figure 13 above and the use case diagram in Figure 14 below is the details with which transporters interact with the FRA system, namely, it is possible for a transporter to assign different drivers to different vehicles. That level of tracking becomes very important towards the food traceability goal.

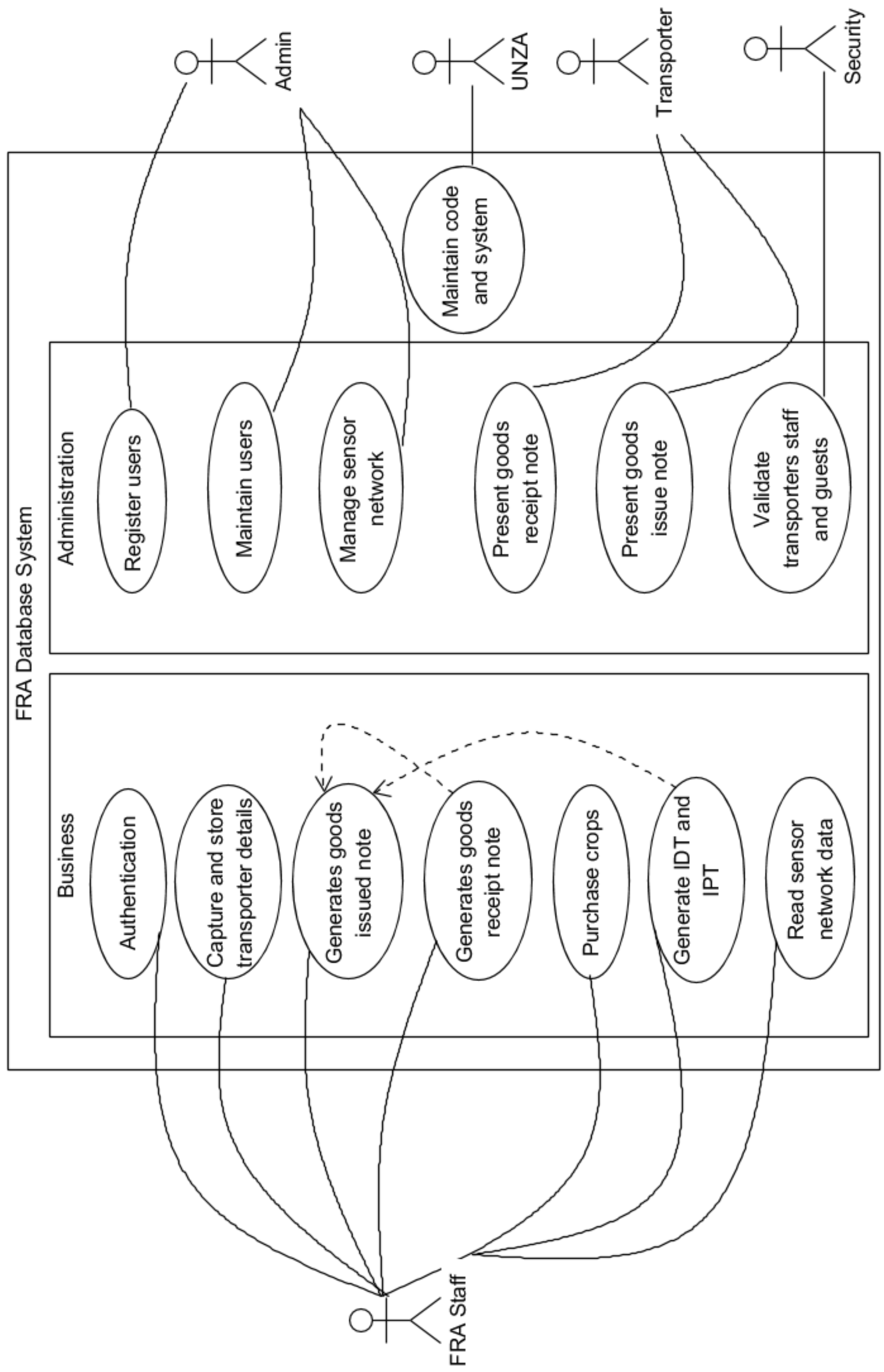

Figure 14- FRA database use cases

3.4.1.2. Goods Receipt Note and Goods Issued Notes

FRA stores the information about received goods or in this case received grain in a form called the good receipt note which can be seen in the appendix. When the transporter arrives at a warehouse and their details are captured, the goods are inspected from a form termed the inter-depot transfer document or the inter-provincial transfer document these two forms are accompanied with a goods issued note from the warehouse or depot from which the goods were sourced. Because the transporter is part of the FRA business processes, the good being transported come from within the FRA domain. For this reason, we created a table that keeps track of the goods, transporter and driver. The goods receipt note table also stores information related to the origin of the goods. The origin of the goods is obtained from the supplier table. Once good are purchased by FRA staff as evident in the use case diagram, they must be tagged with the supplier information. This information is then propagated into the goods receipt note table via a join as one goods issue note requires to have zero or one supplier. In this case, zero or one is important as a transitional phase in order to allow FRA to put processes in place in order for them to begin capturing suppliers. This offers some level of traceability of the grain within the FRA ecosystem. Figure 15 below shows key tables that were designed to be used in the goods receipt and goods issue business processes.

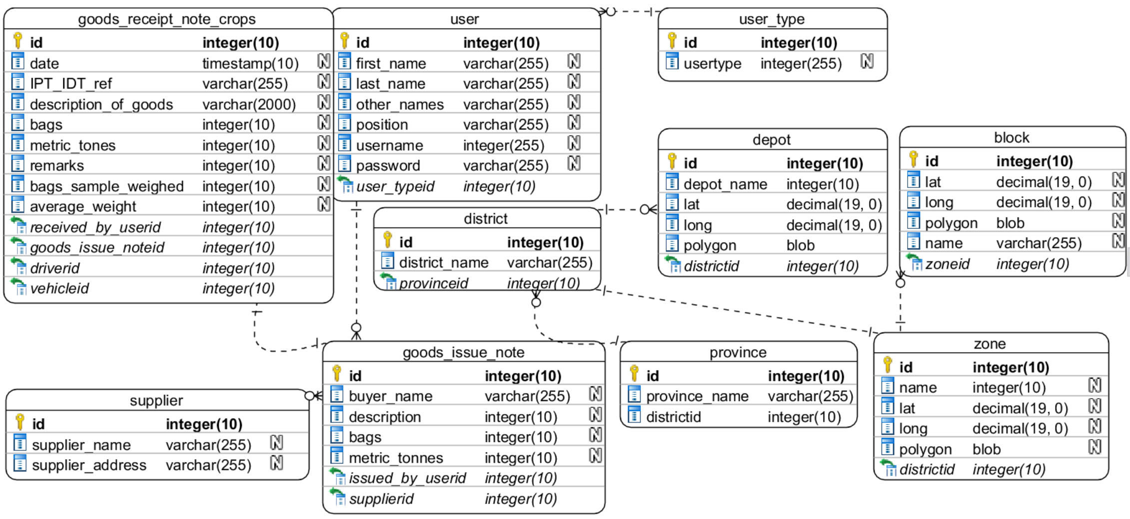

Figure 15- ER diagram of goods receipt notes and goods issue note

3.4.1.3. Geographical Setup

FRA structures its sourcing system into a hierarchical manner. The smallest units in the hierarchy are villages, followed by camps, blocks, districts and finally provinces. This structure is also used by the Farmer Input Support Programme or FISP(Ministry of Agriculture and Livestock no date). It is a well formulated structure that could further enhance the food traceability goal as grain would be able to be tracked to a village and subsequently a farmer. The tracing of food may have several benefits as highlighted in the introduction. Below are tables designed according to the zoning mechanism employed by FRA.

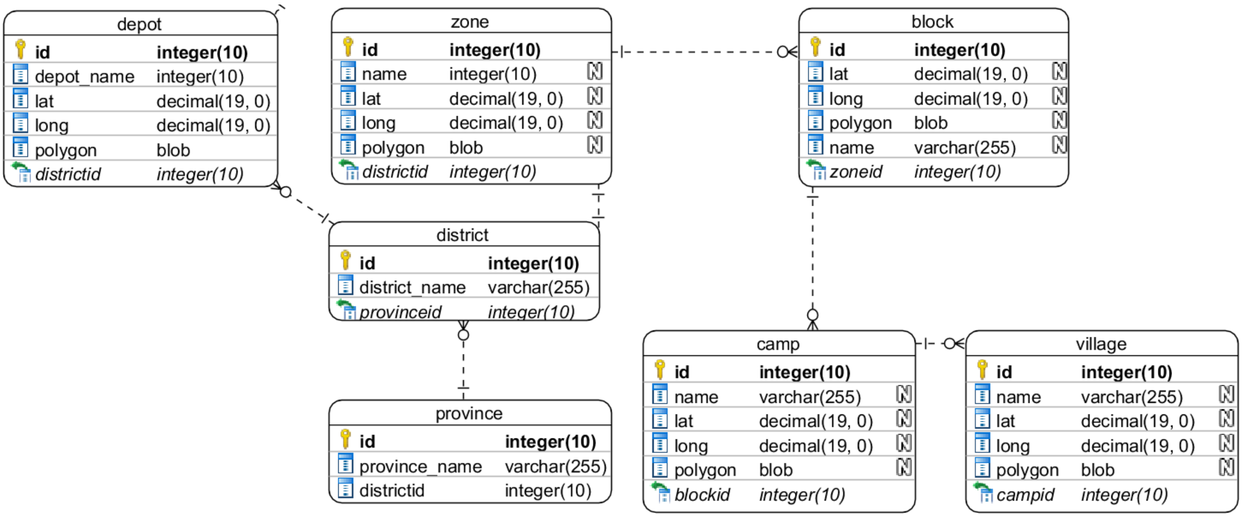

Figure 16 - FRA zoning tables

The hierarchical structure of the zoning is visible in Figure 16 above and is further elaborated in Figure 17 below which represents the zoning hierarchy from the smallest FRA business unit to the largest.

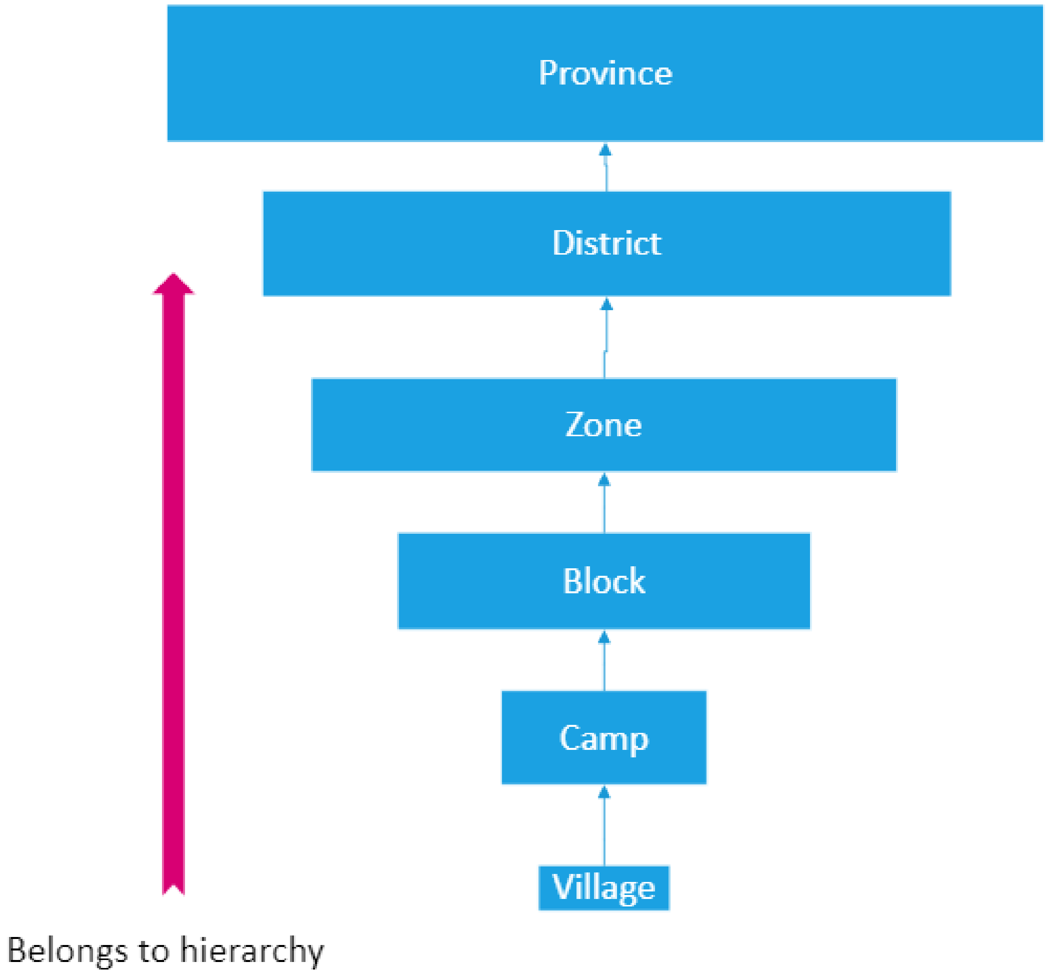

Figure 17 - FRA zoning hierarchy

3.4.1.4. Depot Transfers

FRA regular carries out inter-depot transfers of grain. This is because of their hierarchical structure of the sourcing system as discussed in the previous section on geographical setup. FRA has warehouses at district and provincial level. A transfer may therefore happen at depot level which can also be thought of as district level and it can also happen at provincial level when grain is moved from one depot belonging to one province to another depot belonging to a different province. A depot transfer can therefore either be an inter-depot transfer (IDT) or inter-provincial transfer (IPT). Naturally, depot transfers are performed by FRA staff but actions carried out by transporters who use various vehicles and various drivers. This may be an important point in case analytics are required in the future. Figure 18 below shows the depot transfer table.

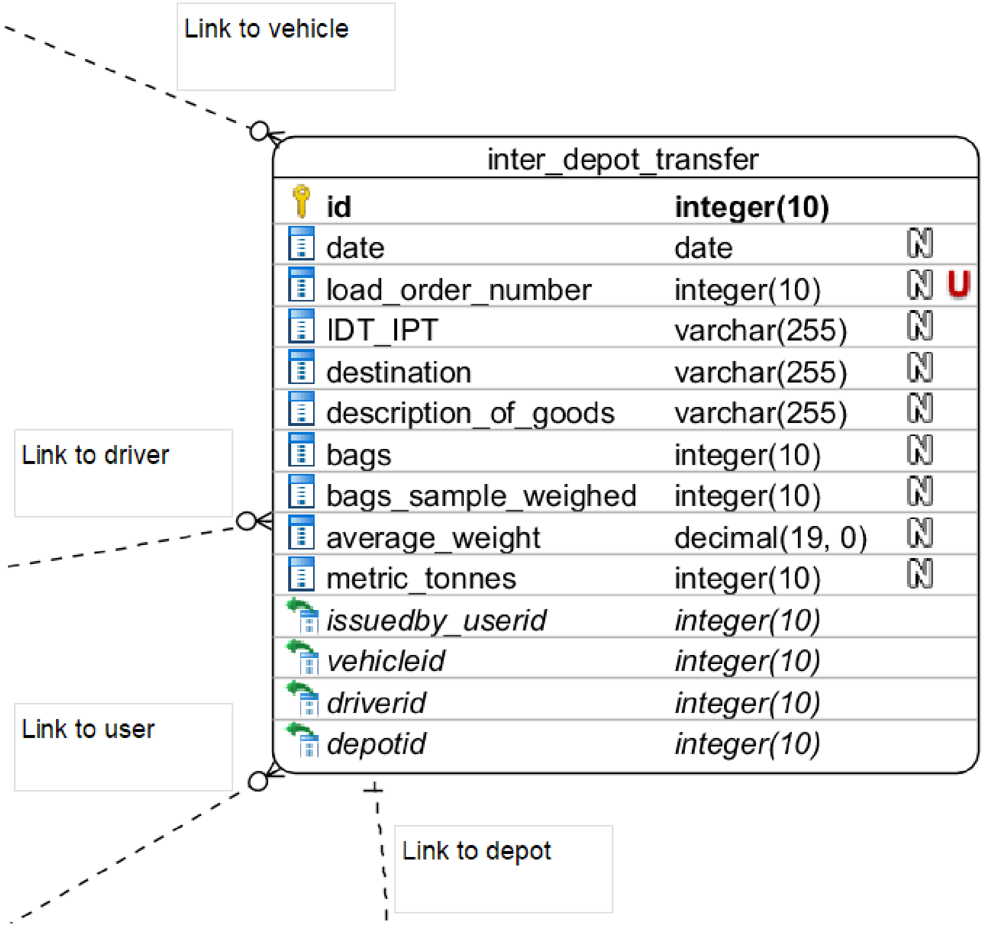

Figure 18 - Depot transfer table

3.4.1.5. Tallies

Tallying is probably one of the most important functions that is performed at FRA. Tallying is concerned with ensuring that grain or stock is accounted for whether it is being sent or received at a warehouse. Tallying usually occurs at provincial and sometimes district level. When goods are sent or received from FRA, they either come from or go to a shed. Hence transporters that arrive at FRA with their inter-depot forms or inter-provincial forms and goods issued notes will be directed to offload or load their stock from one or multiple sheds. Tallying involves checking that items have been loaded or offloaded and finally a supervisor approving the transaction. The tally process begins as soon as the truck enters the FRA premises and the security capture the transporters information. This document is only closed once the transporter exits the premises hence several users update the tally sheet. A table was designed to take care of all the multiple users' requirements including multiple accesses. Figure 19 below shows the tally sheet table. For the associated form, refer to appendix B, figure 57.

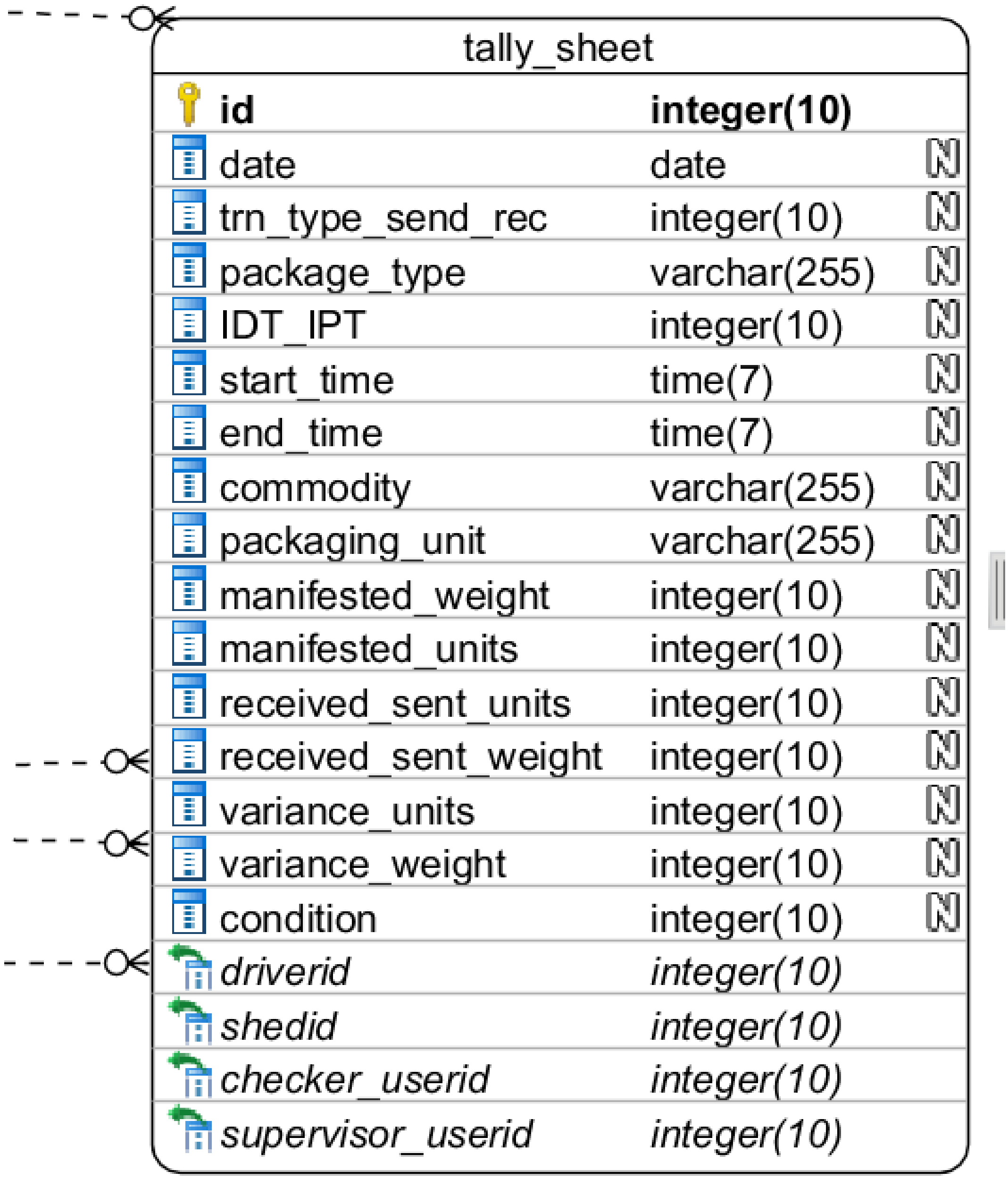

Figure 19- Tally table

The tally table has several fields which may require explicit explanations and those that are deemed unclear are provided below;

3.4.1.5.1. Trn_type_send_rec

The filed name is a short form of "transaction type send or receive". This field is used to specify what kind of transaction this specific tally sheet refers to. FRA either sends or receives stock and those details are input into the system.

3.4.1.5.2. Package Type

The package type is specified by input of the physical packaging structure of the package. This could be packaged in bags, crates or containers.

3.4.1.5.3. Inter_Depot_TransferID

IPT_IDT is a short form of referring to the inter-depot transfer form or the inter-provincial transfer form. As FRA only receives stock at its main warehouse from satellite depots, all incoming or outgoing packages need to be accompanied by the inter-depot transfer form or inter-provincial transfer form.

3.4.1.5.4. Manifested_Weight and Manifested_Unit

These as the names suggest are what is written on the manifest from the source or destination of the goods. The manifest in this case is the goods-issued note which indicates what kind

3.4.1.5.5. Start_Time and End_Time

The start time is the time at which the transporter arrives at the warehouse with the goods while the end time is the time the transporter leaves the warehouse without the goods. This process is reversed in case the transporter actually arrives at the warehouse to collect the goods.

3.4.1.6. Farmer

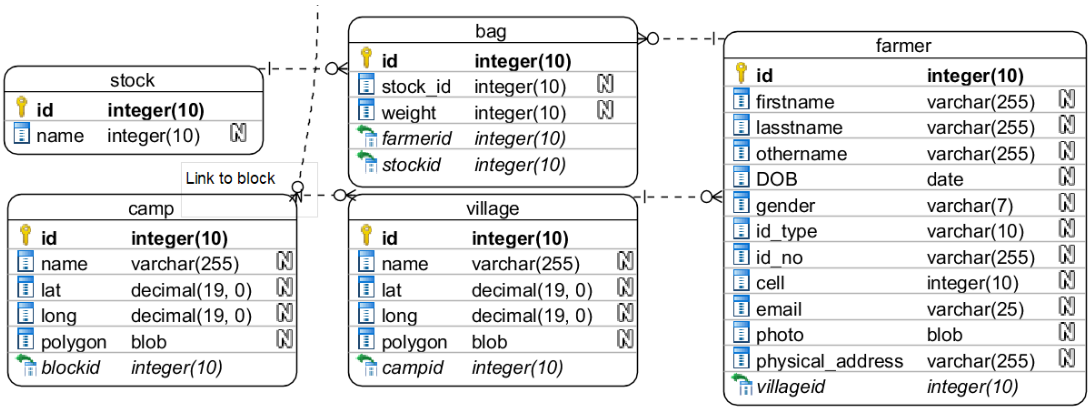

Figure 20 - Farmer interactions tables

Figure 20 shows the farmer ER diagram and associated relationships. The farmer is where the crops originate from. FRA buys from farmers or individuals but these should ideally belong to or come from a specified location so that the food can be traced up to a village setting. A village need not necessarily mean a typical village setup with grass thatched houses but is the least zoning hierarchy in the FRA zoning scheme. A village may even refer to a neighbourhood within a city that has been zoned and classified as a village under the FRA naming convention. With the famer details contained in a database, registration only needs to happen once and the collected data may someday become invaluable towards data analytics and planning. It is visible from the table above that the farmer sells produce to FRA in designated bags. The produce is also a stock type that FRA agrees to purchase. It should be noted that FRA does not buy any and every type of crop. There are internal processes which let FRA decide which crops to purchase in a particular farming season.

3.4.2. Alternative Database Model using Blockchain

A further approach was explored as to the possibility of using Blockchain as the database model for the FRA business processes. The conclusion is that while the country may not be ready, Blockchain technology certainly needs to be considered and further research carried out. Using a mixed methods research approach, we explored the proliferation of data centres in developing countries and rely on past literature in order to define a conceptual model for the optimized evolution of national data centres. We then built a model and glide path for the progression of national data centres towards a true decentralized cloud platform benefitting from a shared economic model using Blockchain technology and discuss each of the steps with pros and cons. We looked at practical implementations from other governments and corporations.

For the protection of data, we recommend further research into the best possible encryption standard to follow. Since we are proposing a potentially future proof true decentralized national data centre, we propose serious consideration into the use of more advanced data encryption standards to outlast progress in computers that make use of Shor's(Gerjuoy 2005) algorithm and Grover's algorithm to crack current encryption standards(Mavroeidis et al. 2018). More work will be required in the future in order to improve cryptography post quantum computers, this is an important point to note if data security is fundamental and future proof.

3.4.2.1. Honduras Land Titles on Blockchain

Honduras is a mostly Spanish speaking republic in Central America with a population of 9.1 million(World Bank Group 2017). The case of Honduras is particularly interesting as this country opted to use Blockchain technology exclusively for the storage of land title(Heimler, Marissa 2017), unfortunately, the project stalled but it is our view that we will continue to see such initiatives as the drive towards resource optimization, efficiency and the shared economy is pushed world over. The Honduras government partnered with a company called Factom(Factom, Inc 2016h) and their Factom Blockchain(Singh & Singh 2016) which is in its most basic term a distributed database or ledger with Blockchain technology as the underlying foundation. Factom builds application on top of their Blockchain and supports large transactional volumes.

3.4.2.2. Swedish Land Registry using Blockchain Technology

In early 2017 The Swedish Mapping, Cadastre and Land Registration Authority embarked on a conceptual project to record land title information and real estate transactions using Blockchain technology for the following reasons(Lantmäteriet, Landshypotek Bank, et al. 2017);

- Faster and more transparent transactions
- Elimination of the possibility of selling a property more than once
- Greater security for users of the system due to the possibility of independent verification of transactions

3.4.2.3. Glide Path to True Cloud Architecture

Traditionally, governments embark on e-government projects with the following stages;

1. Set up national communications network
2. Set up data centres

The two stages highlighted above have a significant capital and operational expenditure. We make the argument that both (1) and (2) above have been set up or are in the process of being set up by private corporations in several countries around the world. Governments can use regulation to leverage existing IT infrastructure thus reducing their capital expenditure and relying more on operational expenditure in order to achieve the goals of e-government.

The characteristics of true cloud architecture are highlighted below;

- On demand self-services (Gong et al. 2010)
- Broad network access
- Resource pooling
- Fault tolerance
- Rapid elasticity
- Measured service
- Multi Tenacity

We construct a matrix in Table 7 and explore through literature the best model to follow.

Table 7 - Analysing generally accepted characteristics of true cloud computing

Selecting the Best Data Centre Model			
Characteristic	**Research question**	**Methodology**	**Statistical analysis**
On demand self-services	Which data centre model has the quickest deplyment	literature review	mean
Broad network access	Which data centre model provides the best	literature review	mean
Resource pooling	Which data centre model provides the best model for	literature review	mean
Fault tolerance	Which data centre model provides the most optimal	literature review	mean
Rapid elasticity	Which data centre model is	literature review	mean
Measured service	Which data centre model	literature review	mean
Multi Tenacity	Which data centre model can accommodate several	literature review	mean

The questions in Table 7 above were answered by looking at 3 main contributors to the field of cloud computing and what their conclusions were on the best model that fit the required characteristics of cloud computing. The contributors that were purposively selected include Massachusetts Institute of Technology (MIT) due to their research in methods of improving time complexity of messages in data centre environments(Jonathan et al. 2014i), Gartner research(Gartner 2015a) (Gartner 2015b), due to their track record in consistently providing factual data and research into technological trends and the United States Department of Homeland Security because they were selected as a case study for this proposal. For details as to the findings, refer to Table 8 below. It can be noted that none of the contributors selected in the synthesis matrix actually mention Blockchain as an option for a data centre model. We make the argument that Blockchain data centre models being built on top of cloud infrastructure is therefore a superset of what is termed cloud based. Blockchain based models can encompass private clouds, public clouds and hybrid clouds. They can also offer the major requirements in data centres such as the platform, the security and the networking, all provided as a service. Interestingly, the model suggested by MIT in decentralized storage, but centralized management does not restrict the use of Blockchain technology as applications can be built with flexibility in the mode of networking because we can view Blockchain solutions as software defined networks. We therefore propose that since cloud-based approaches are preferred in most data centre leverage matrix, a Blockchain based approach provides the most optimal model. We propose that any government wishing to implement a national data centre immediately consider the Blockchain option for the following reasons;

- Blockchain provides true Platform as a Service, Database as a Service and Infrastructure as a Service. This is further highlighted in the choice by the analyzed contributors to mostly prefer a cloud-based approach towards key characteristics of data centre requirements.
- The infrastructure costs of Blockchain implementations for data centres are much lower.
- The time to deployment is the quickest as governments may leverage already existing Blockchain implementations.
- Citizens and private corporations within a country may be incentivized to contribute free resources to the countries Blockchain hence easily providing freely available scalability and additional computing resources.

Table 8 - Selecting the best data centre deployment model

Research question	Gartner research	US Dept. Homeland Security	MIT
Which data centre model has the quickest deployment time?	Hybrid clouds are favoured.	Outsourced	-
Which data centre model provides the best networking model?	Software defined networking is preferred.	Cloud	Distributed storage, centralized management
Which data centre model provides the best model for resource pooling?	Cloud computing.	Hybrid cloud	-
Which data centre model provides the most optimal time and space complexity?	-	-	Distributed storage, centralized management
Which data centre model is easily scalable?	Open platforms	-	-
Which data centre model has the least cost?	Cloud based	Hybrid cloud	-
Which data centre model can accommodate several users easily?	Cloud based	-	-

We propose that any government's data centre or data centres that scale an entire country must adhere to the above generally accepted characteristics of true cloud systems. Our glide- path therefore proposes a 4-stage process towards the evolution of government's data centres into Blockchain architectures. We have already looked at the case of the United States which has advanced data centre implementations but was forced to embark onto optimization projects. We have also analyzed the case of Zambia where the data centres are currently being deployed. From the study of the US case, it will save governments progressive amount of money if cloud-based approaches are used towards data centre implementation and optimization. Our four, stage approach is as follows;

- Establish a data centre or use an existing data centre
- Backup data on a third-party network and outsource selected services
- Use a hybrid cloud model with Blockchain integration
- Outsource the data centre and progress towards a true cloud model and shared economic model relying on Blockchain technology

Most governments are currently in the first phase while the United States Government is in the second phase. With the current projects being implemented by various departments within the US government, we can clearly see that they are heading towards the third stage of the model. We argue that further progressing towards the fourth stage or immediately implementing a national data centre using the fourth stage approach will reduce overhead and introduce further savings making the governments IT infrastructure more agile, robust, redundant and easily scalable with minimal operational overhead.

3.5. Remote Sensor Network Development

In developing the remote sensor network, we came up with the requirements specifications which were derived from our first objective in determining the challenges that are faced by the Food Reserve Agency in its grain marketing business. Each of the requirements were addressed by further research and looking into literature as to what types of technologies could be employed in order to address the challenges. We then mapped the business processes initially using a descriptive approach as can be seen in previous work by Cynthia Muyunda. The business process mapping was further implemented using the business process mapping notation standard version 2.0 or BPMN 2.0. We then went on to develop a detailed database and normalised it up to the third normal form or 3NF using UML's entity relation standard. Eventually, we built a model using our derived platform architecture for the remote sensor network and simulated the working using Amazon Web Services and the MathWorks MATLAB Thingspeak API. We then partly designed and built a working prototype using various products such as the Mosquitto Broker, Raspberry Pi, wearable GPS sensor, Wi-Fi, Zigbee, digital temperature/humidity and pressure sensor. The software and code that forms the cornerstone of the remote sensor network was designed and developed using agile software development techniques as we had to have several deliverables presented to the stakeholders seeing as this was a sponsored project. The continuous engagement of the sponsor was important hence the agile approach was the preferred choice.

3.5.1. Illustrative System Modelling

The remote sensor network was illustratively modelled in a modular approach. This was done so as to avoid restrictions on the kind and type of modules to be used. The bus connectivity of each module was not defined and were left open to interpretation.

3.5.2. Functional Prototyping

In order to prove the practical implementation of the remote sensor network using android things, 2 prototypes were developed. An iterative development approach was used. The first prototype transformed into the second prototype. This method was only useful to the author in order to assess practicality of the overall project as there was little contact with the technical team at FRA. It is suggested that for a third prototype, an agile development method be adopted so as to have constant input from the end user during the development life cycle.

3.5.3. Real time environmental monitoring

Real time monitoring of the FRA facilities entails that data should be available on demand. While trying to keep costs low and ensuring the requirement is addressed, we employed the use of existing mobile phone networks as the means of achieving ubiquitous communication across all facilities. Our research also led us to the Universal Access Project by ZICTA which we believe will be able to provide a cost-effective wide area network for use by the Food Reserve Agency's remote sensor network.

3.5.4. Data caching on site

This requirement stems from the fact that a system that is deployed in a remote location may be far from competent human intervention in case a backhaul network fault occurs. In light of that, it becomes imperative that data that is captured on site may need to be cached until such a time when the network becomes available once more. This requirement was met by the use of an active aggregator that supports OS-like functionality. The Raspberry Pi 3 was therefore chosen as the best aggregator.

3.5.5. Low power requirements

Power is major factor in all systems deployment and a remote networked system may have stringent power requirements. It is important to enable independent power supply or provide reliable backup and not rely on utility power. Also, the components that are used in the system should have minimal cost implications as concerns power. The entire power requirements were limited to a maximum of 5VDC and a minimum of 3.3V DC. Such low voltage requirements coupled with low current requirements can provide very long battery life. The details as concerns the best configurations for the power requirements were not looked at and this was left for future work.

3.5.6. Usage of a third-party wide area network

A third part wide area network would be required as the cost of building a countrywide network is prohibitive and unnecessary given that several parties have already invested in wireless mobile networks that span almost the entire inhabited country. The sensor network requires an uplink network in order to relay the collected data. Because of the ubiquitous nature of the GSM, 3G and LTE networks today, mobile phone telecommunications companies provide the best possible platform that can be used for communication purposes. As was previously discussed, in chapter 2, the characteristics of a platform are that they facilitate communication between multiple users and they serve multiple users. The traditional mobile phone network exhibits the two characteristics of a platform hence is useful for our design approach. For the purpose of the prototype, we used dynamic IP address assignments to the device. However, in the real-world, each remote sensor aggregator which in this case was the Raspberry Pi would have to have a unique identifier on a public network or a private network. In our case, the remote sensor network connects to a server on the internet to which information from the local environment is sent. As was previously discussed from the model, the server need not be centralized but can be a pool of servers working together. At any one time, a certain server is the master server and uses the master IP address that all aggregators refer to. After the master server receives the information from the remote sensor network, the data is synchronized across the other servers for the high availability feature of the system.

3.5.7. Cloud storage

Cloud storage is desired because the storage capacity requirements may be procured as a service or used and paid for as required using a metered or quota approach. We estimate that over time, there will be huge amounts of data generated from the remote area network and the data may need to be stored for an indefinite period of time. TO that effect, there would be unreasonable costs incurred in the constant upgrade of data centres to store the generated data and process the data for meaningful information. In order to prevent that, a cloud-based approach is desired.

3.5.8. Data redundancy and resilience

Data redundancy and resilience is critical if data is required to be stored for an indefinite period of time. The usual method employed by several organizations is o backup their data in cold storage and when required, the data can be copied back to active systems for analysis. This we believe brings about inefficiencies and time wasted in loading the data from cold to active storage. With the current trend in cloud computing, there are several methods that can be employed to back up data and some methods include hybrid clouds and even Blockchain implementations.

CHAPTER FOUR
RESULTS

4.1. Baseline Study

The baseline study was carried out and this presented us with the challenges faced by FRA in the current manual systems employed in grain marketing and grain storage. The baseline study determined that FRA has challenges such as manual report generation, no connectivity to remote warehouses, inability to track stock on demand, theft, spoilage of stock due to lack of environmental monitoring. There were challenges faced in collecting the empirical data that we hoped would ascertain whether the Food Reserve Agency would require ICT's in order to better manage the grain marketing business. We had over 150 questionnaires prepared but a poor response rate of only 44%. We therefore decided to substantiate the data with purposive visits to the agency's management offices and warehouses. Interviews were conducted with key staff and further insight was used to create a detailed description of the business processes which were mapped and can be seen in a paper by Cynthia Muyunda and Jackson Phiri(Muyunda & Phiri 2016). For the purpose of this paper, we focused on creating a solution for all locations that are used to store grain.

Details of the questionnaire may be found in appendix B. Below we show the results from the baseline study with 68 respondents out of 150 questionnaires issued.

4.1.1. Category of Staff Interviewed

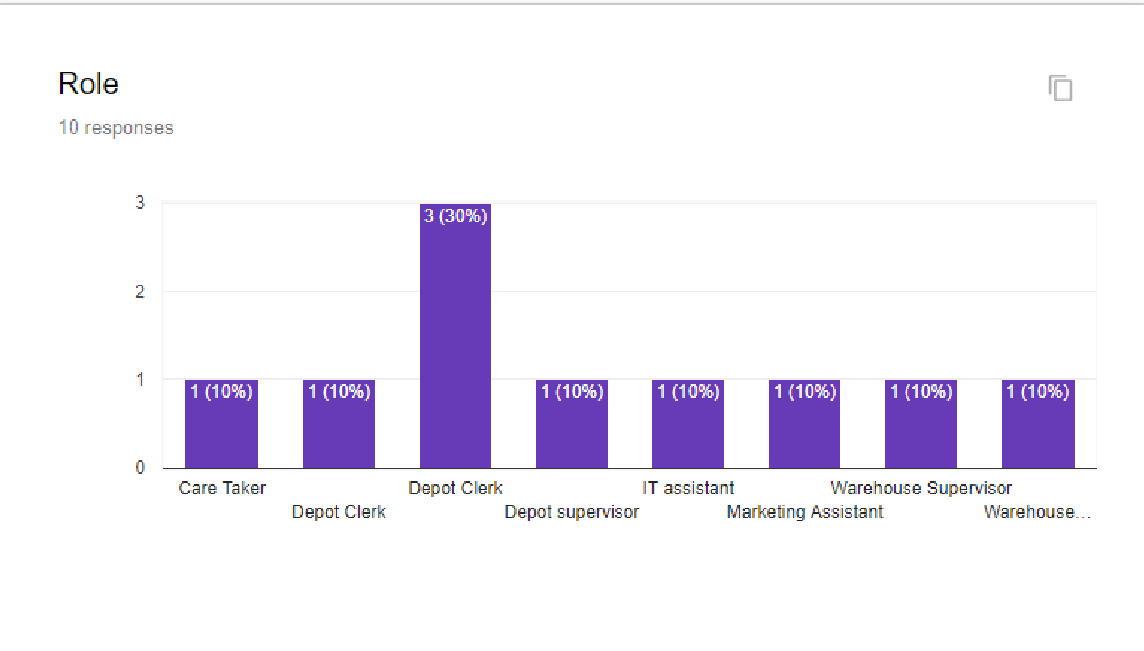

Figure 21- Category of FRA staff interviewed and responded to questionnaires

We wanted to find out what broad category of staff we were interviewing and so we asked them to indicate their roles. Only 10 respondents revealed what they did at FRA with the results indicated in Figure 21 above.

4.1.2. Location of Staff

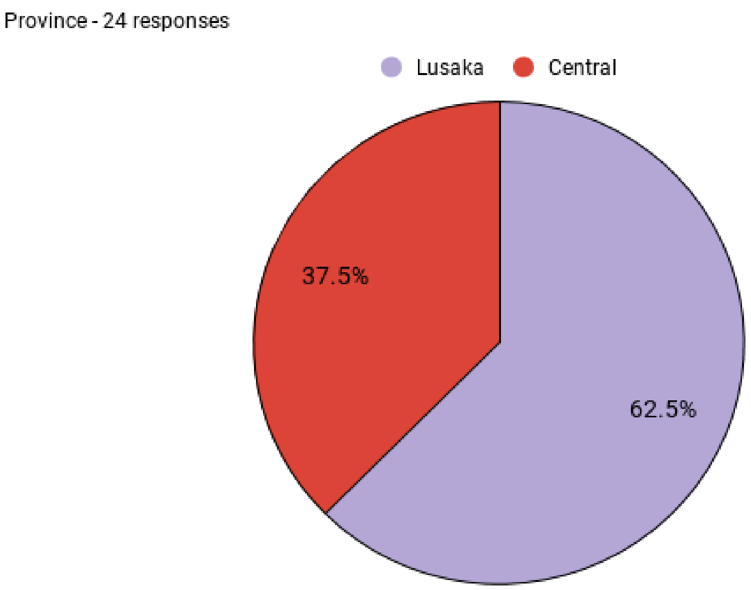

Figure 22- Location of FRA staff participating in study

Figure 22 indicates that most of the respondents were from Lusaka province.

4.1.3. Use of ICT's by FRA

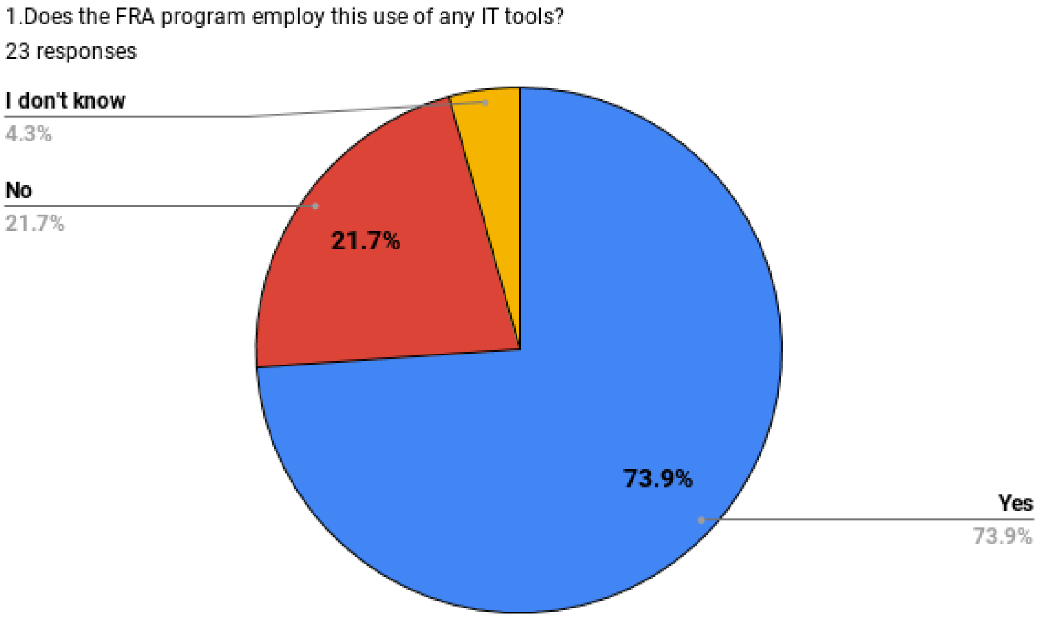

Figure 23 - Use of ICTs by FRA

In the Figure 23 above, we wanted to know whether the employes participating in the study knew if FRA employed the use of ICT tools. In order to get a clear undertanding of what they thought ICT tools were, we asked the following question in Figure 24 below;

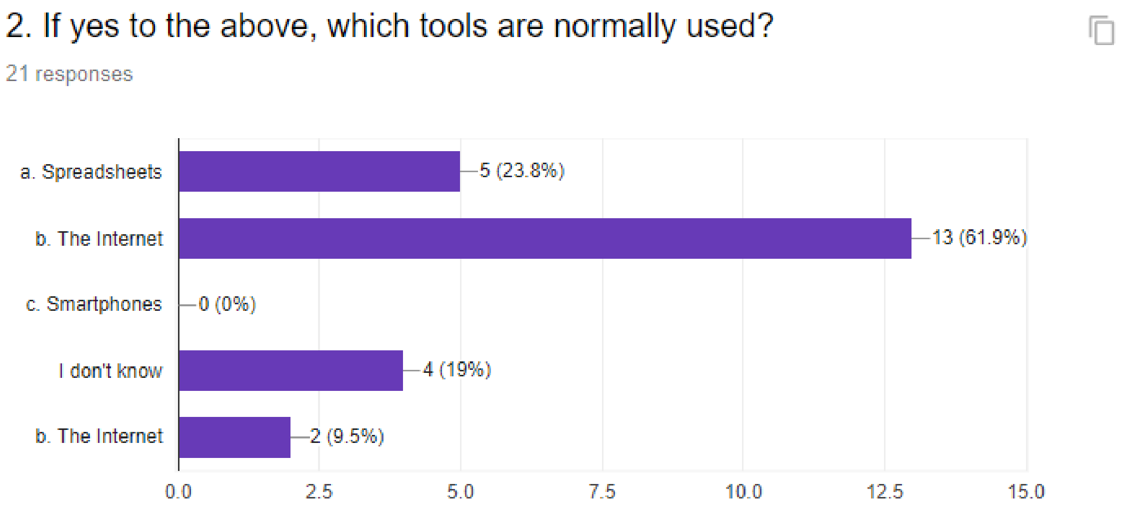

Figure 24- What ICT tools are used by FRA

Figure 24 above shows that the majority of the respondents thought ICT tools refer to the use of the internet.

4.1.4. Stock purchasing

We determined that FRA does not purchase stock all year round and that the activities are seasonal. This is important information that will determine the kind of implementation of the remote sensor network. A system can be designed that only works during the grain purchasing and grain storage seasons. In Figure 25 below, we can see that the majority of the staff did indicate that FRA does not purchase stock all year round.

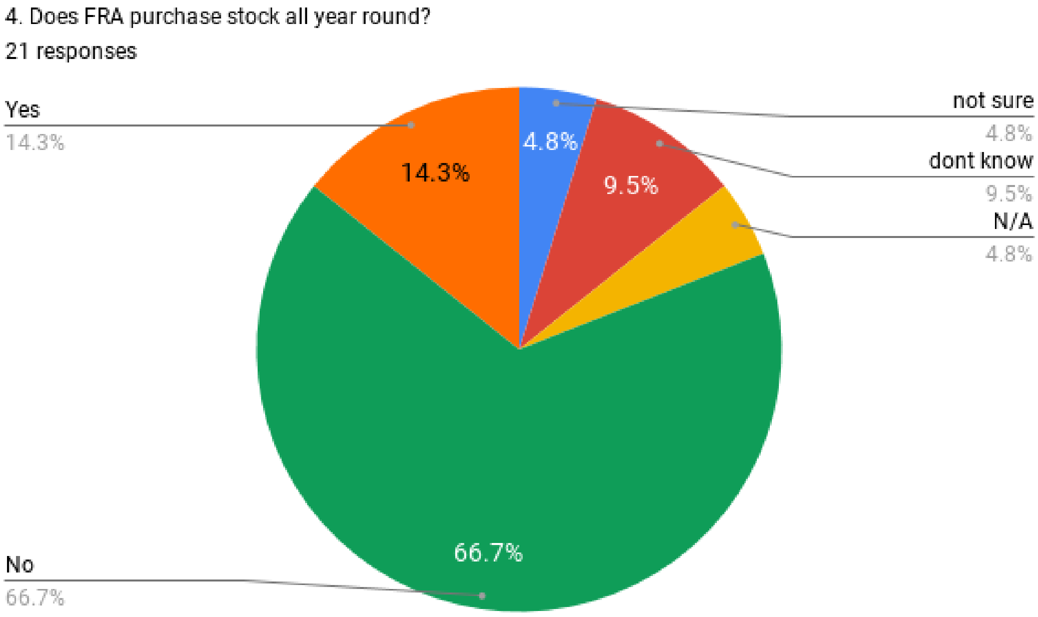

Figure 25- Does FRA purchase stock all year round?

4.1.5. Problems faced by FRA

Figure 26 below shows a general set of problems that the FRA staff defined. We can see that the majority of issues are concerned with poor communication between FRA staff.

poor roads, poor communications facilities (2)
Work from the regional and district office. There is traffic between the two offices. Whether is a challenge. Rain during commuting
Counting bags by kabamba's, manual labour offloading bags. Stacking
Drivers ramming into stacks, loaders not getting paid. loaders down tools.
Dust, no dust mask
Materials, work suits
Poor road, poor communication network, poor communication with farmer
Poor road network to and from purchasing sites, poor communication network services
poor communication network, poor road network where maize is purchased
poor communication network, poor road network
poor road network, poor communication network
None

Figure 26- Problems faced by FRA

4.1.6. How FRA keeps track of inputs

We determined that manual methods are used in order to keep track of stock at FRA. Figure 27 below shows the kinds of responses that were received.

10. How do you currently keep track of inputs to farmers?

16 responses

PRCN (5)
I dont knoe
Counting stacks, in and out. Stack cards, tell which track came on a certain day and how much was brougt
Physical counting in warehouse and from book balance
count daily and reconcile with the books
Procure receipt certificates
PCRN
Produce receipt and certification node number
Documentation on purchses
inventory system
PRCN, inter depot transfer, goods received note
Book records

Figure 27- How FRA keeps track of input

4.1.7. How Transporters are monitored

In the pie chart shown on Figure 28, we can clearly see that respondents indicated that there is no method of monitoring transporters that FRA uses. Basically, they are unable to predict when transporters will deliver grain to their warehouses.

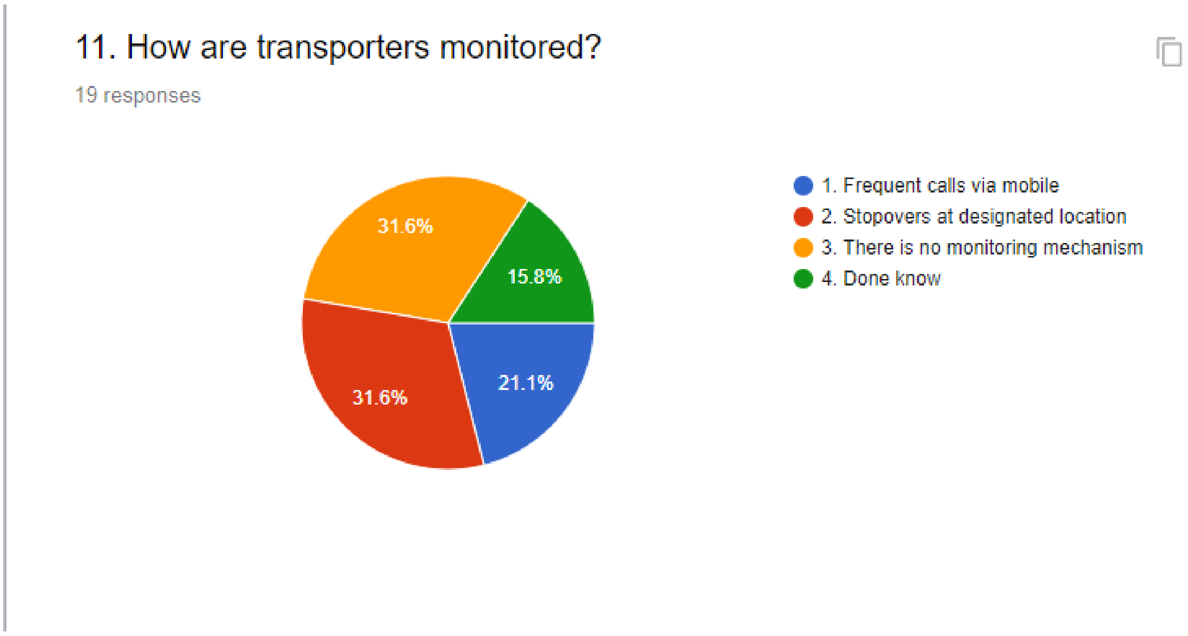

Figure 28- How FRA monitors transporters

4.1.8. Monitoring of the Environment

We determined that there is some mechanism by which FRA monitors the environment at which stock is kept. This monitoring mechanism is dependent on available staff to manually monitor and measure while recording inputs at random time intervals. The pie charts in Figure 29 and Figure 30 clearly show from the respondents that no environmental monitoring system currently exists at FRA warehouses. Without such a system, it will be difficult for FRA to maintain FAO and ISO standards on grain warehousing management.

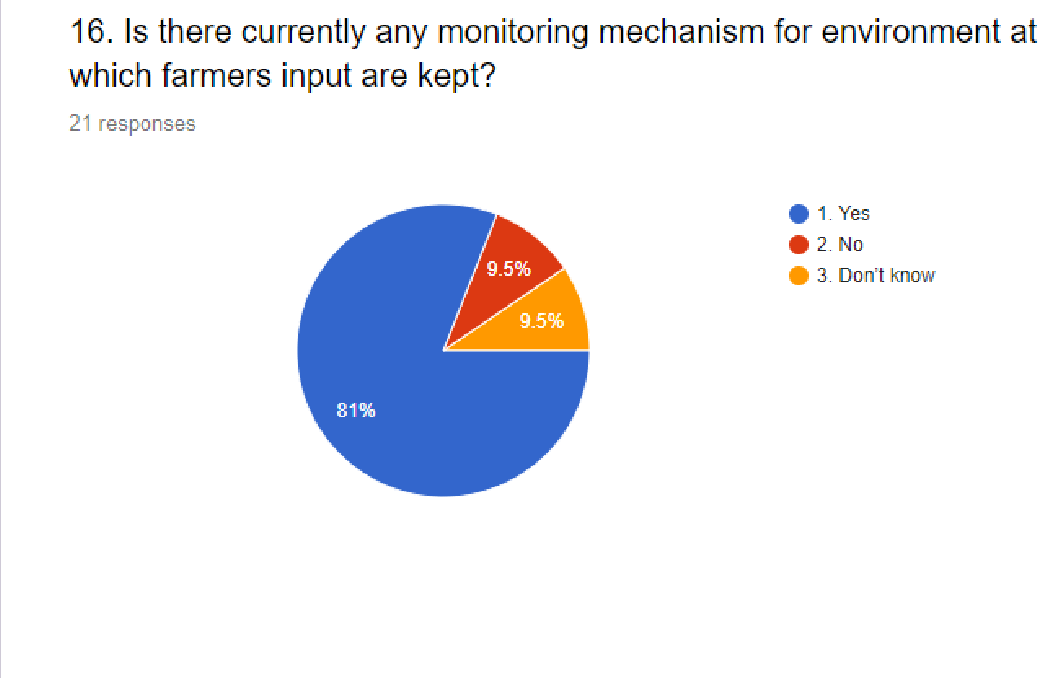

Figure 29- Environmental monitoring

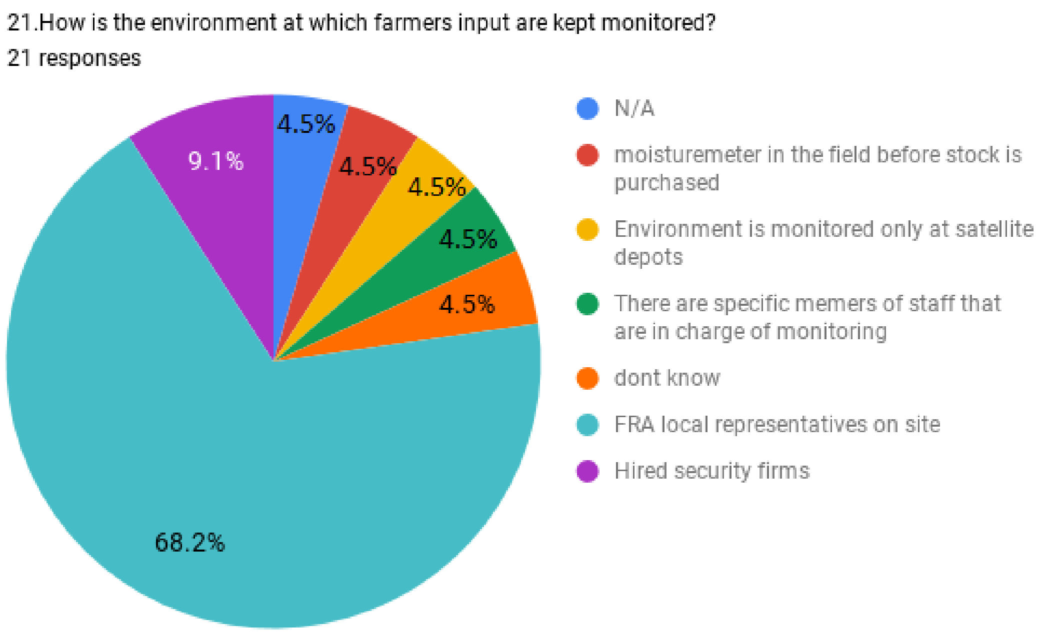

Figure 30- How the environment is monitored

4.2. Business Process Mapping

An ISO/IEC standard was used for the business process mapping as described in the methodology. The business processes and business rules were inferred by referring the vast amount of information that was collected during the baseline study phase of the research. It was clear than FRA did not have clearly documented references for their day to day operations but each particular department handled certain processes which were then outputs to be used by the next departments or members of staff. It was clear through verbal interviews and the questionnaires that were presented that it was possible to map the FRA business processes. Initially, a descriptive approach was done and this was eventually extended using standard business process modelling notation.

4.3. Database Development

The database was developed using standard UML and constrains enforced following rules inferred from the various forms that were provided. The entire database can be seen in appendix D. UML was selected because it provides an easy to read object reference model which makes replicating the database an easy activity. The database and its relationships were normalised to the third normal form in order to remove the unnecessary replication of data while enforcing primary and foreign key relationships.

4.4. Remote Sensor Network

The remote sensor network development had a twofold approach. It was first simulated it using Amazon Web Services and then eventually developed it using the Mosquitto Broker, the MathWorks MATLAB Thingspeak API and a simulated cloud network. The first method was selected for the proof of work implementation. The AWS console for IoT supports software-based simulations for the publish/subscribe MQTT protocol while the Mosquitto broker and Thingspeak API requires actual working code and installation on a server for it to be used. Therefore, we had a platform for testing and a platform for the testing and implementation of the prototype.

In further trying to develop a low-cost remote sensor network solution relying on cloud computing, we begun with the requirements and components for such a network and these were sensors, aggregators, an uplink and downlink network and a cloud-based storage service. The most usual method of creating a sensor network would be to connect a series of sensors to a personal area network and an aggregator that has a GSM shield. This GSM shield may support the common mobile network technologies such as GSM, 3G, LTE and most recently 5G. The GSM shield is connected to the aggregator and an operating system is used in order to communicate with the shield and upload data to a remote server. Our implementation replaced the GSM shield with a built in Wi-Fi network interface card on a Raspberry Pi. Basically, it does not really matter what kind of network is used in order to upload or get information from a server as long as the implementation is modular, various components may be swapped for preferred types, refer to our model in figure 14 where the implementation is communications network agnostic. Popular devices that are used for the aggregators are the Raspberry Pi or some other device with acceptable computational power and computer architecture as there would have to be some sort of operating system installed on the aggregator. We looked at the common setup and wanted to know whether we could build a low-cost solution based on the common architecture and possibly improve upon it. We came to the conclusion that since the Android operating system supported native sensors, we would use it and its high-level API calls as the operating system of choice for our remote sensor networks aggregator. The advantages were found to be as follows;

- It already supports native mobile functionality
- It supports native calls to supported and unsupported sensors with custom drivers
- It can be stripped down to its most basic requirements for the sensor network
- It works well on mobile phones hence has low power requirements
- We could fabricate a device by removing unnecessary features such as the screen, speakers, mic etc. in order to remain with the basic operating system functionality
- We could make use of the USB port in order to interface with devices that required serial communication

Figure 31, Figure 32 and Figure 33 below show a very early iteration in which we attempted to connect sensors to the mini USB port of an Android device. Here we used an Arduino as an aggregator for the sensors and the Android device as the processor and communications network interface. The Arduino microcontroller was connected to the Samsung Galaxy S7 smartphone via a universal serial bus on the go cable or USB-OTG. The sensors in the figure include a temperature/humidity sensor and a motion detector. We also made use of the location sensor on the Android device in order to provide localized data

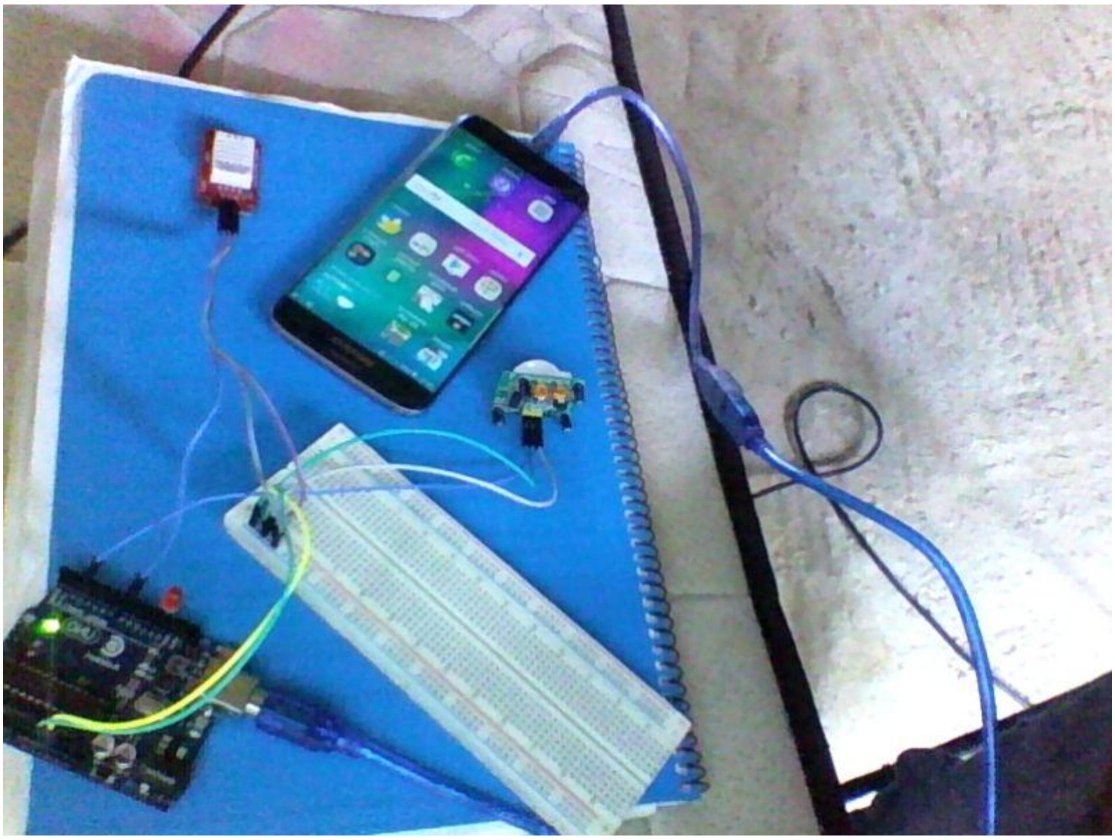

Figure 31- Early version of sensor node with mobile phone for network connectivity

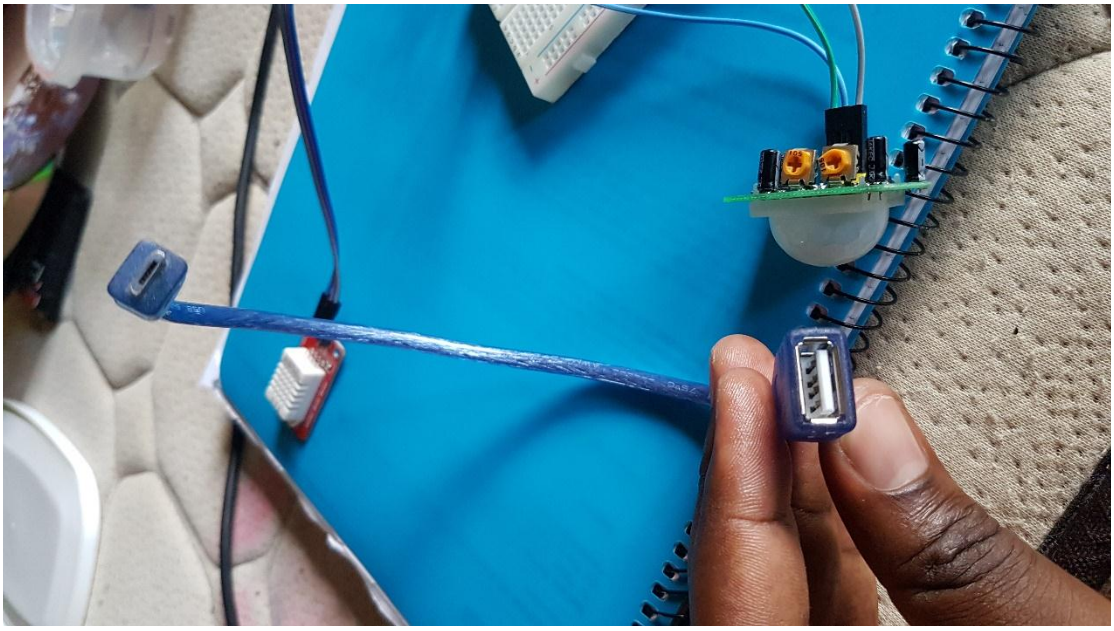

Figure 32 - Early prototype using USB OTG cable

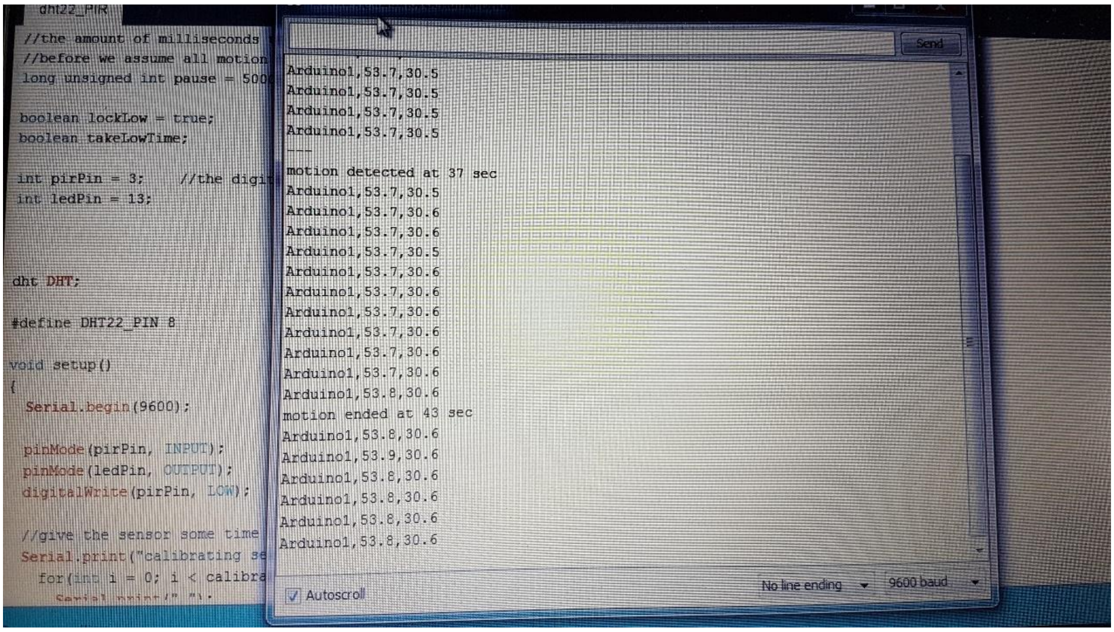

Figure 33 - Output on computer from early prototype

In Figure 33 above, it can be noted that the Arduino output values obtained from sensors connected to it onto an external display. In this case, the display was either a laptop computer or the mobile phone.

While still trying to develop the remote sensor network, Google announced in December 2016 that they would be releasing an operating system called Android

Things that would support several common hardware platforms which are commonly used in sensor networks. This meant that the research took a turn from using the Android operating system meant for mobiles to using Android Things. There were obvious advantages such as;

- The Android Things platform was specifically built for the internet of things
    - Low cost
    - Low power
    - Native support for the Google Cloud Platform
- Support for several types of commonly used sensors and the ability for a developer to create custom drivers
- Native support for mobility functions such as GSM, 3G, LTE and Wi-Fi
- Support for popular prototyping devices such as the Raspberry Pi 3.

For the purposes of our development, the Raspberry Pi 3 with the following sensors and support peripherals was used;

- BME280 Temperature and humidity sensor
- Motion sensor
- Wearable GPS sensor

Figure 34 below shows the BME280 integrated digital sensor connected to a Raspberry Pi 3.

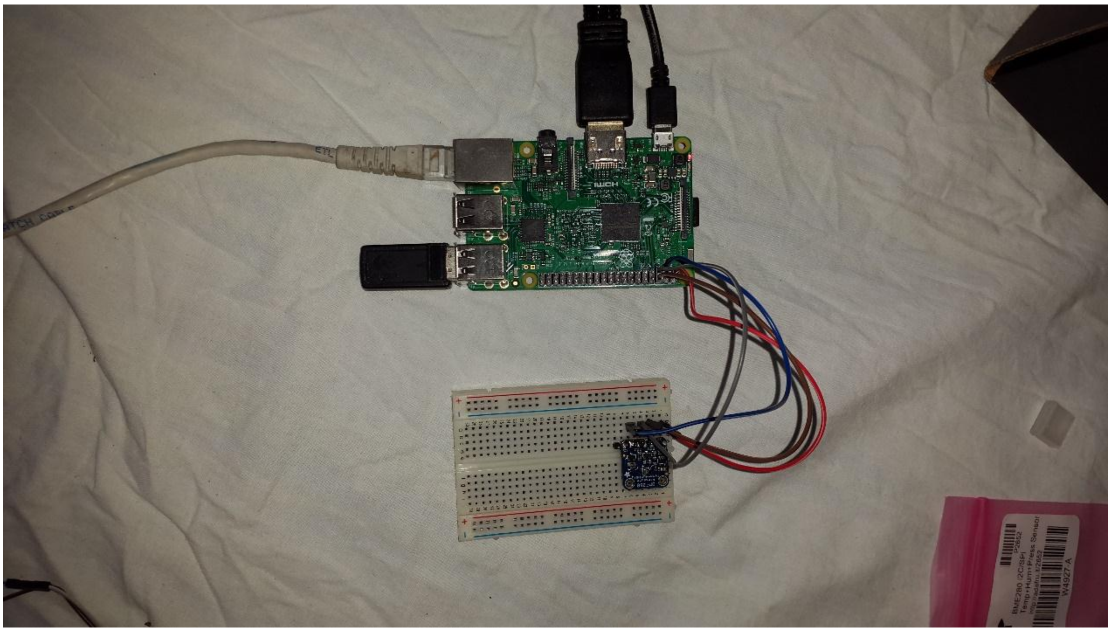

Figure 34- Raspberry Pi 3 with Temperature, humidity and pressure sensor

A free version of the Amazon Web service AWS and the Google Cloud Platform were also used and the Mosquitto Broker was installed on each in order to collect the sensor data, another service that was used was the MathWorks ThingSpeak API. Below in Figure 35 is a model of the remote sensor network setup.

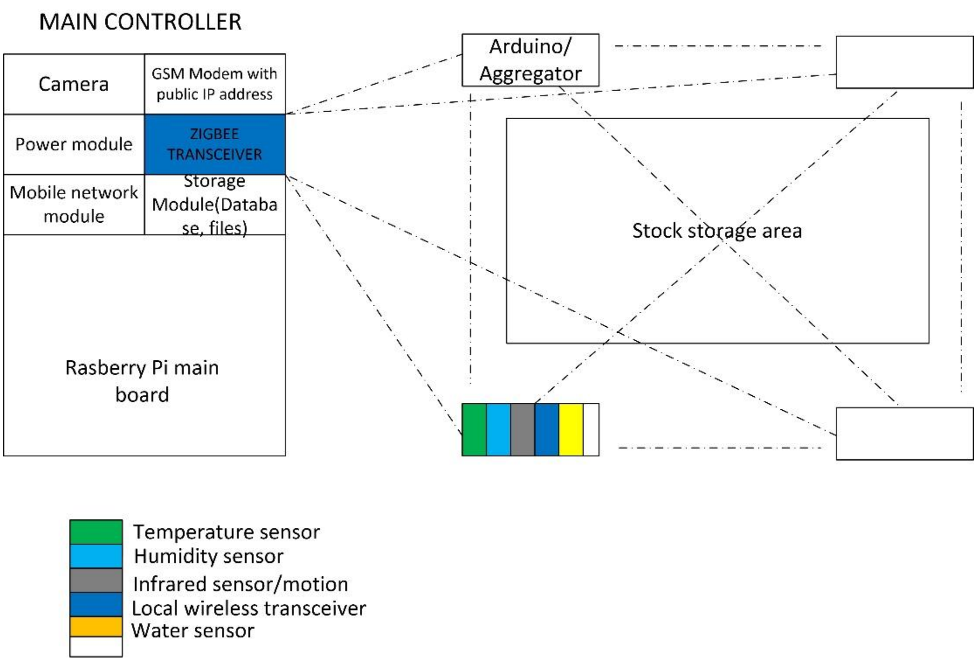

Figure 35 - Remote Sensor Network Model

We have only been able to implement a network with temperature, humidity and location information as a proof of concept. With our modularized design, one could add all manner of sensors and even actuators.

For the purpose of future deployment of the entire system, we developed a model for a platform and we have previously discussed the advantage of a platform in that it can be used not only by the intended user but by any other users. Our model may be utilized as a service using the Zambian government's national data centres for storing and processing the sensor network data. Figure 36 below shows our system model.

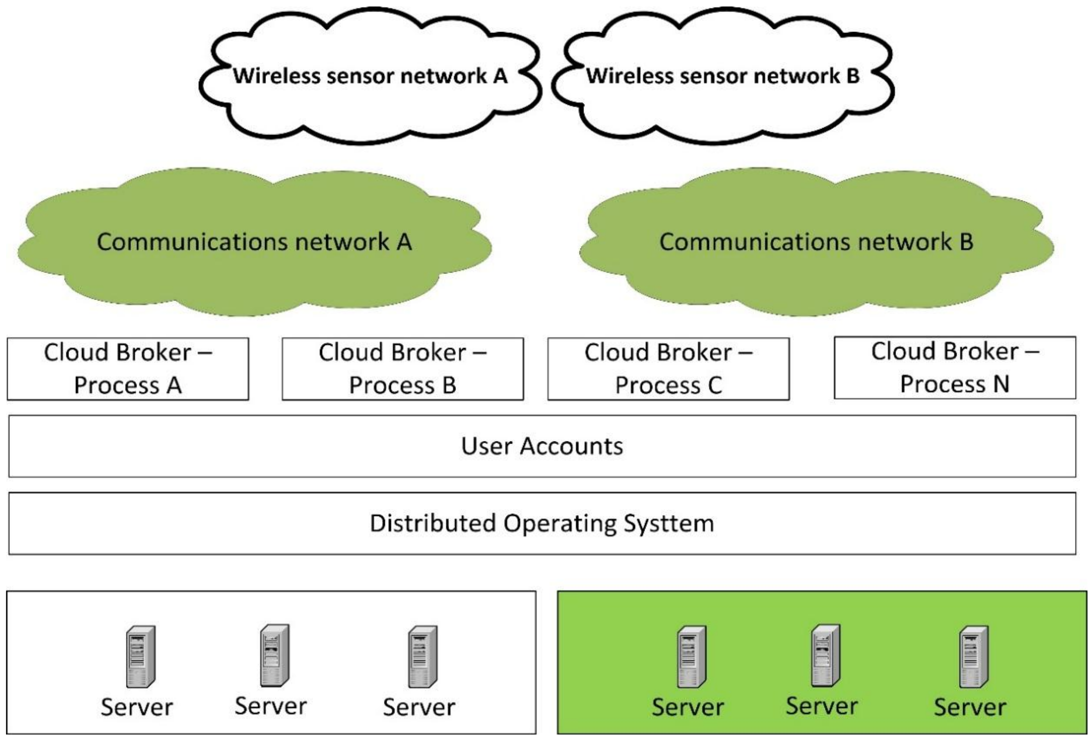

Figure 36- FRA universal remote sensor network architecture

We propose the use of cloud computing in our model for reasons previously discussed in section 2.2.2. The Food Reserve Agency in Zambia can leverage already existing data centres and indeed the national data centre which aims to make computing resources universally accessible to all government agencies and organizations. Our model is a layered architecture where each layer may be composed of different product types with standard application programming interfaces native to the selected product. A user may for example decide to use any manner of distributed operating system in existence or yet to be implemented. A user may also decide to use any other message broker besides our prototype selection, the Mosquitto broker. This design gives true independence as to the flavor of the products selected for deployment onto our standardized platform.

4.4.1. Prototype of the Remote Sensor Network

A prototype of the remote sensor network was developed and tested. Different hardware components were required in order to have the proof of concept working. The prototype was developed using a Raspberry Pi model 3B development board as the main controller according the sensor network model. The main controller had a Wi-Fi connection and a mobile phone network was used in order to relay information to a remote server. There was no GSM shield component used on the main controller but since the development board supported Wi-Fi, a wireless access point was used in order to let the aggregator communicate with the remote cloud service. The BME280 integrated temperature, humidity and pressure sensor as described in chapter 2 was used and a generic GPS sensor in order to determine the location of the device. The prototype relied on MathWorks's Things Speak API which used http GET requests to transmit internet of things (IoT) data. Below is a picture of the working prototype that was showcased at the 2018 Lusaka Agricultural and Commercial Show between July 27th and August 2nd, 2018.

Figure 37 - Sensor Network Prototype

Figure 37 above shows what the typical development setup of the prototype would look like. Shown above is the Raspberry Pi 3 Model B microcomputer, a BME280 integrated sensor, a 5V portable power source, a 7-inch display connected to the Raspberry Pi, a 17-inch desktop monitor connected to the internet that displays graphically the information collected by the sensor. In order to make it more interesting, a quick response code was added to the board so that visitors could scan the code and also have access to the shared results that were remotely captured by the sensor. For the purpose of the showcased prototype, the HTTPS protocol was used for communication over the internet. For the final development, it is recommended that the MQTT protocol be used as the communications protocol.

Figure 38 below shows the second prototype iteration of the remote sensor network. The display as indicated in the figure below is optional. Going by the work model of the remote sensor network, a display is only required at the point at which data is analysed. The display indicated on the prototype was used merely for convenience purposes.

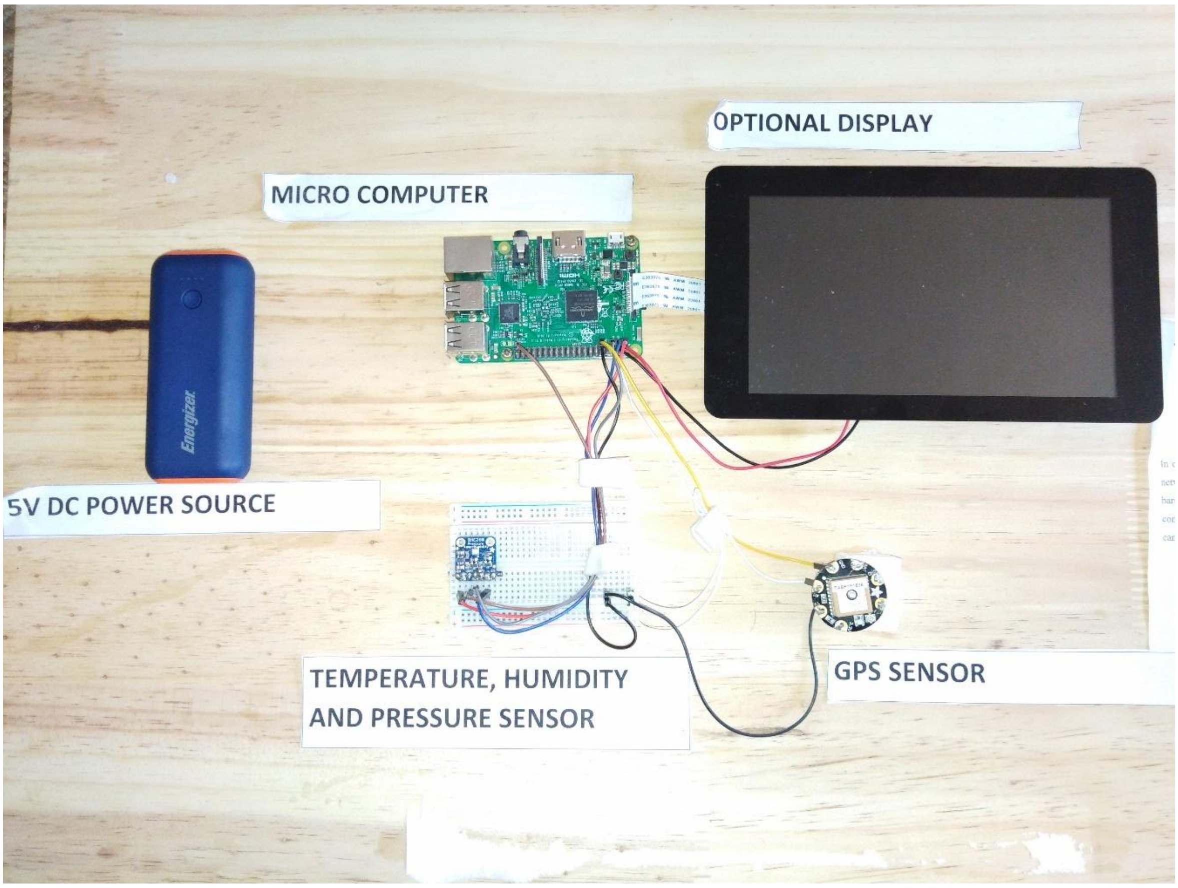

Figure 38- Close up of 2nd Prototype

The two Figure 38 above and Figure 39 below shows snapshots from the ThingSpeak website where sensor network data was polled to and processed using IoT standards with a graphical display. In the Figure 40 and Figure 41 below, we offer a different perspective of the graphical interface for the collected sensor data.

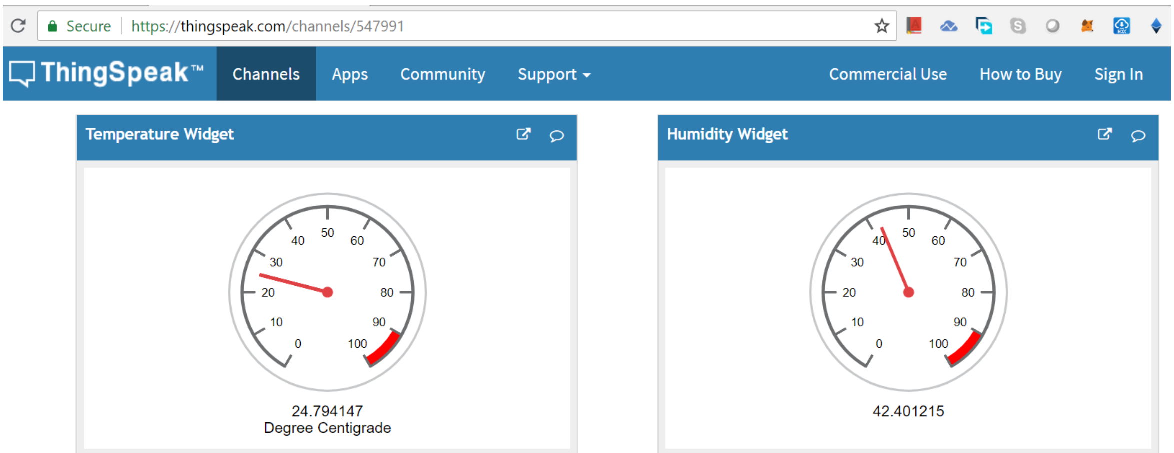

Figure 39 - IoT Widgets, Temperature and Relative Humidity

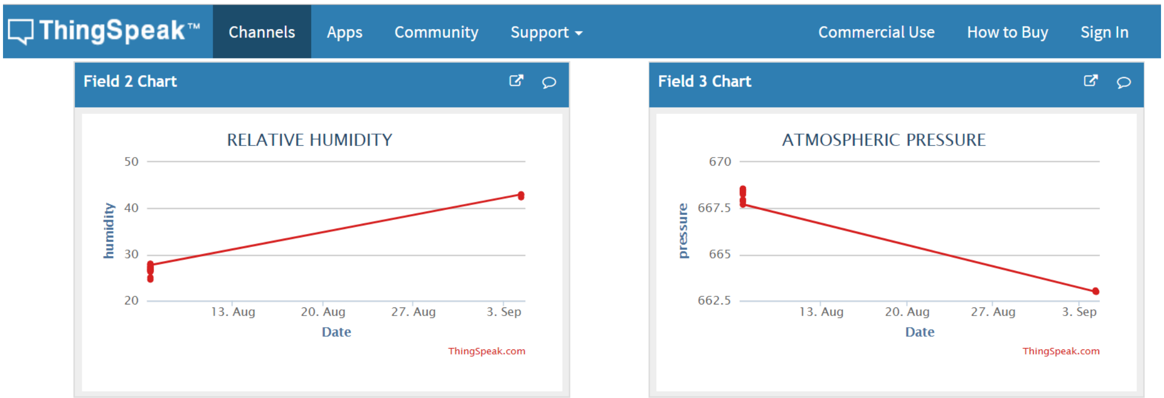

Figure 40 - IoT Chart Showing Temperature and Relative Humidity

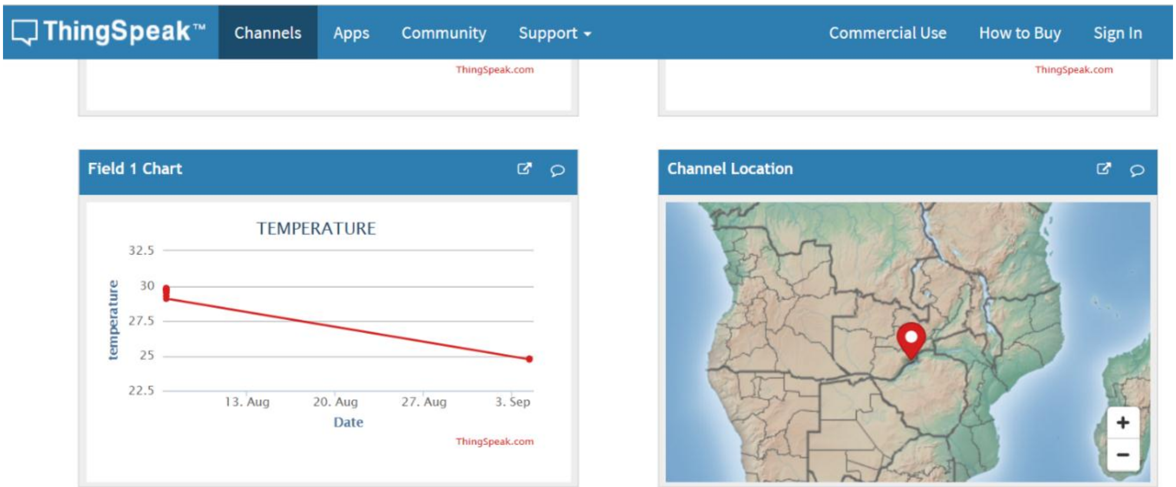

Figure 41- Showing Temperature and Location of Sensors

4.4.1.1. Connecting the Raspberry Pi to a network

The raspberry Pi 3 had a built in Wi-Fi receiver that could be used to communicate with a local network on site. The Wi-Fi receiver in this case was the best option as a mobile network enabled Wi-Fi hotspot was used in order to provide the uplink connectivity. The problem of using a dynamic IP allocation scheme is that the assigned IP address to a specific sensor may only be known thorough access the Wi-Fi access point router settings and the device of concern. This may be impractical for real world deployment. Fortunately, as discussed in the literature review, regional and global IP addressing standards are beginning to move away for network address translation and telecom companies have been advised to ensure that all users on their networks are assigned publicly accessible IP addresses. This entails that every internet accessible subscriber on mobile networks worldwide will be uniquely identifiable at least via an IP address. It is also possible for an organization to obtain static IP addresses which are linked to subscriber identification modules. However, for the purpose of showcasing a working prototype, the concerns highlighted were ignored and further research may be undertaken.

4.4.1.2. Installing the Application on the Prototype Hardware

An IP address on the Raspberry Pi 3 aggregator is required in order to communicate with the development computer. The Raspberry Pi 3 is able to obtain an IP address via DHCP. So, in this case, an Ethernet cable is connected to the development computer on one end and to the Raspberry Pi 3 on the other end. DHCP needs to be enabled on the development computer for this to work. Because it may not be known what IP address has been assigned to the Raspberry Pi 3 from the development computer, an IP scanner was used in order to determine what devices are connected to the development computer within the configured DHCP IP range to the LAN interface that is connected to the Raspberry Pi 3.

An alternative to using DHCP is to use Windows Internet Connection Sharing or ICS. As a windows 7 machine was used as the development platform, internet connection sharing was enabled on the development machine in order to force it to assign an IP address to any devices that are connected to the LAN port. Internet connection sharing assigns a static IP address to the LAN interface of the development computer. Afterwards, an IP scanner is used to search the network range assigned to the development computers LAN interface. The IP scanner determines all other IP addresses within the network that are connected to the development computers LAN interface and have been assigned a DHCP IP address.

The above methods were used for the beta version of Android Things OS running on the Raspberry Pi Model 3 B. As of the stable release version 1.0, Android Things supported obtaining an IP address via a simple GUI that pops up as soon as the device is booted up. The GUI supports basic functions such as updating the OS, configuring the date and time and setting up Wi-Fi. The GUI is of course optional and applicable only where a display is used. For the purpose of the prototype, a tiny 7-inch display was used in order to be able to have access to the GUI which sped up the development and troubleshooting process. In a real-world deployment case, the remote sensors would be numerous and located in sparse geographical locales. Hence the methods defined above would be impractical. However, with static IP addresses and GSM shields, a system administrator simply needs to keep track of IP addresses, GPS coordinates and names in order to uniquely identify sensors and aggregators across the entire geographical span.

4.4.2. The Sensors

Below, each of the sensors that were used in the project is discussed for an overview of their capabilities and the reasons that each was selected.

4.4.2.1. The BME280 Sensor

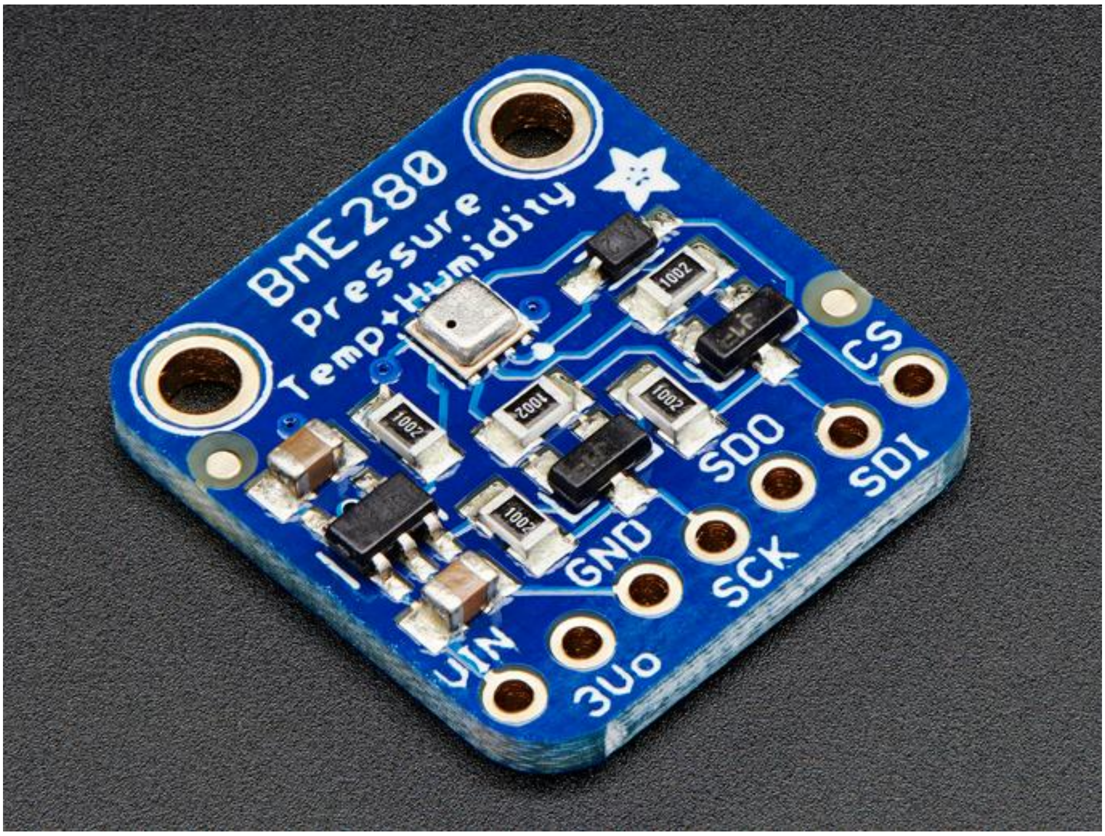

Figure 42- BME280 Sensor

The BME280 sensor, indicated in Figure 42 above is a digital sensor manufactured by the Bosch Company; it is very popular in internet of things applications and wearables. It is also used in several handheld digital devices in order to provide environmental monitoring capabilities. It was chosen for this project due to its low cost, ease of use and native support in Android Things. As can be observed from the perforations on the board, 0.1-inch male/male pins have to be soldered to the board before the sensor can be connected to a bread board or it can easily be knitted into garments with conductor thread. Below in Figure 43 is the completed sensor connection to a breadboard. It has been shown through research that the BME280 sensor is particularly useful when measuring the temperature of air hence had a very good use case for the study(Japhet & Ndai 2016).

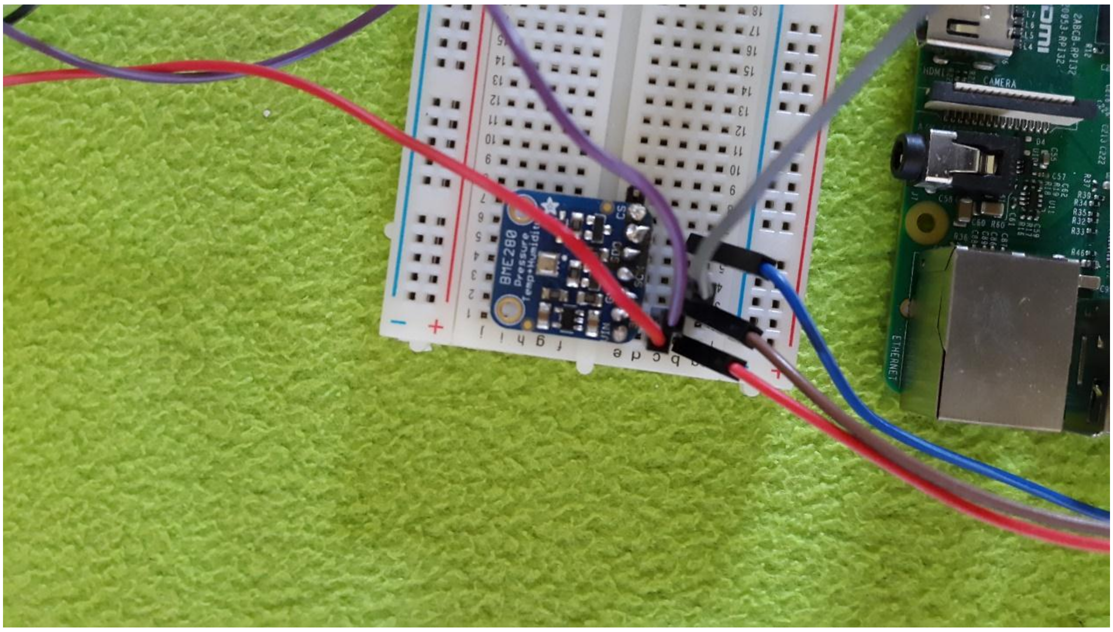

Figure 43- BME280 bread board connection

4.4.2.2. Flora GPS Sensor

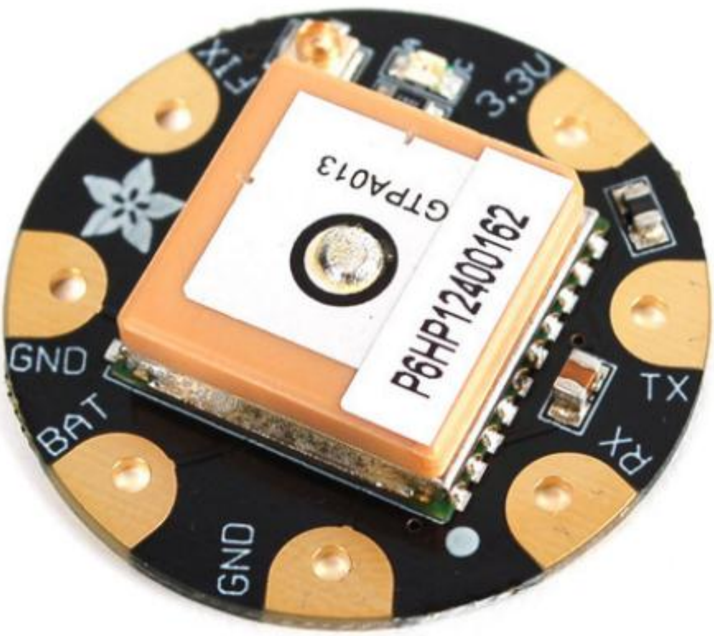

Figure 44- Flora wearable GPS sensor

Figure 44 shows the Flora GPS module that is manufuctured by the Adafruit company and is a wearable GPS module which is very good for outdoor use. It can be powere by a small button cell with a 3.3V requirement. It has upto 66 channels for the GPS antenna and like the BME280 sensor, it has perforations on the board that allow it to either be connected using soldered pins to a breadboard or knitted using conductor threads to garments. It was chosen due to its low cost, low power and compact nature. Though it does not have native support from Googles Android Things operatng system , user drivers can be written using provided user space managers within the Android Things system. Figure 45 below shows the Flora GPS module with connected pins.

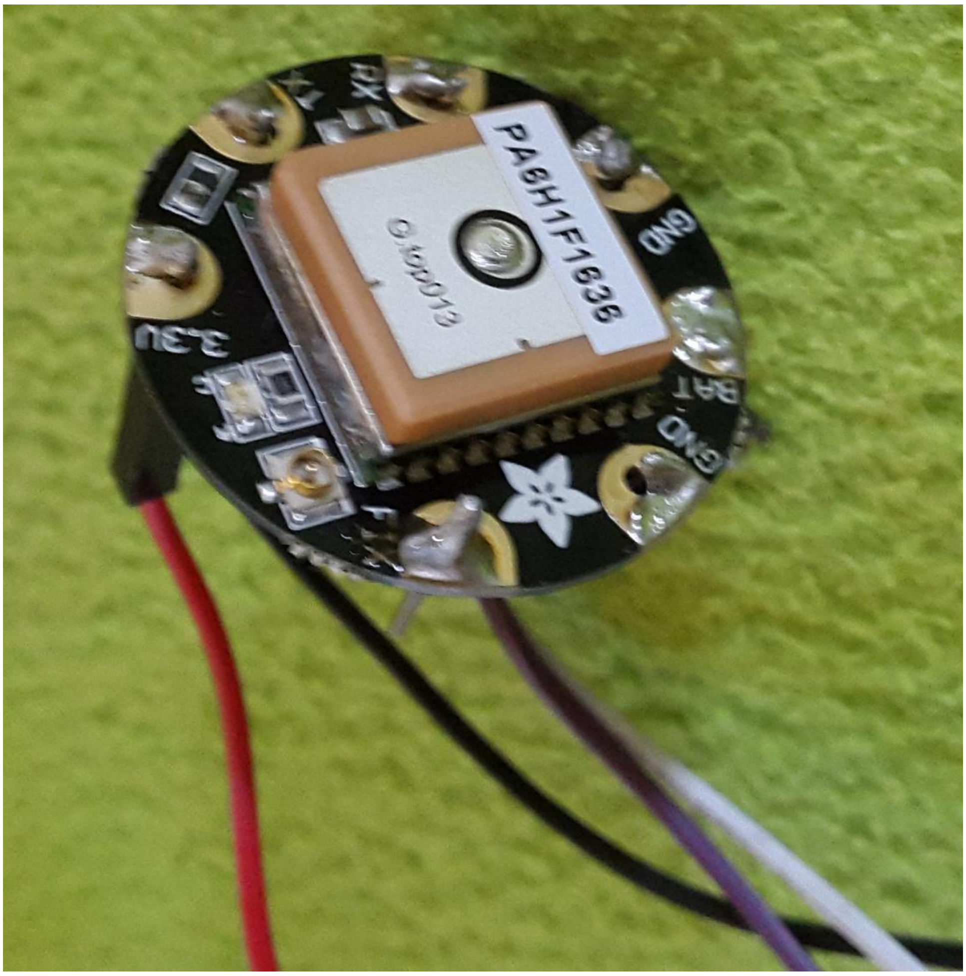

Figure 45 - Flora GPS module with connected pins

CHAPTER FIVE
DISCUSSION AND CONCLUSION

5.1. Introduction

In this chapter we look into the overall research and discuss each of our finding with recommendations for future work.

5.2. Discussion on the Baseline Study

It was clear from the baseline study that a lot needs to be done for the food reserve agency in order for it to meet its mandate in securing the nation's food supply in the short term and creating a sustainable framework for the long-term benefit of the nation. We have proposed a system that can be deployed at all their warehouses and designed it so that it can easily be ported to all types of scenarios due to its modular nature and use of tools such as the standard business process modelling notation of 2013. It must be pointed out that food security is key part of the United Nations 2030 sustainable development goals to which Zambia is a signatory being a member of the UN. In the next section, we discuss the UN 2030 SDG on ending hunger and how Zambia and FRA can align itself to the goal using ICT's in agriculture.

5.3. 2030 UN SDG – End Hunger

Ending hunger is a fundamental goal of the United Nations 2030 sustainable development goals. The second goal of the UN SDG's is "End hunger, achieve food security and improved nutrition and promote sustainable agriculture". ICT for development as concerns to agriculture and as defined the Food and Agricultural Organization, FAO which is a body of the United Nations, involved the implementation and use of information systems for food security. This certainly does go along with our recommendations to begin to implement remote sensor networks and indeed RFID technology as recommended by Cynthia Muyunda in ensuring national and indeed global food security. According to FAO, reliable data about the food in a country leads towards a consolidated view which enables better and informed decisions policies and programmes with regards to the food security of a nation and the word at large(Cafiero & Stamoulis no date).

This research has highlighted a major issue currently being faced by Zambia's Food reserve agency in trying to secure the food industry of the nation and the region at large. While it has been shown through research that ICT;s in agriculture enhance all aspects of the rain marketing business, Zambia has lagged behind in the adoption of such technologies and yet the infrastructure that may be considered enablers for the inclusion of ICT for agriculture are currently available as of late 2017 such as the National Data Centre, excellent coverage by mobile network operators and indeed the Universal Access Project by the Zambia Information and Communications Technology Agency. The Universal Access Project aims at ensuring that all traditional leaders throughout the country are connected to a 2G and 3G network. This, the government believes will connect virtually all the individuals in the country to a mobile network which will make it possible for the government to roll out e-government services for accessibility to all. It must be noted that even the grain marketing business can benefit from the mass rollout of these mobile phone networks. In our case, it makes it possible for us to deploy a remote sensor network in all areas where FRA may have satellite depots present. This assumes that all individuals will at least live in close proximity to a traditional leaders' palace hence have access to the mobile phone network. Satellite deport are also usually entirely located within close proximity of the traditional leaders' premises.

5.4. Conclusion

Food security in Zambia and indeed the Food Reserve Agency can benefit from the use of ICT's in the food value chain. From the study of the two cases of Zambia and the United States presented in this thesis, it can be seen that cloud computing and the shared economy are the apparent goals of e-government, but the implementation approach lacks standardization therefore introducing unnecessary costs associated with the implementation and further optimization of these projects. The largest costs associated with e-government projects are the infrastructure costs which this research argues could be reduced to fractions of what they are today or completely eliminated if existing Blockchain are leveraged. With advancements made in cryptography, cloud computing, data access and storage techniques, governments world over can evolve seamlessly towards true cloud governments by taking advantage of the models implemented in current and future Blockchain technologies. The inherent nature of governments is to keep information in an unaltered state for reference by future generations. The internet and its latest application, Blockchain technologies provide the best solution for the continuation of government.

The choice to use Google's Android Things platform for the development of a remote sensor network is mainly due to the fact that Google has created a platform with advantages that we believe are essential towards the further development and standardization of remote sensor network architecture at both the hardware and software level. The change that we expect to follow is equivalent to that change that followed the smart phone ecosystem following the introduction of the Android operating system which is essentially a software platform and several third parties were able to leverage Android and communicate with other parties through a standardized development environment. It is believed that the Android Things platform will continue to develop and evolve especially since it is open source and this will in turn lead to industry self-standardizing sensor interfaces and API for seamless development and deployment. Our developed proof of concept follows the platforms model and can easily be extended by third parties. As for how to solve the storage of data that is generated from multiple sensors and multiple warehouses, it is believed that cloud-based storage holds the key. For the prototype Google Cloud Platform was used. However, cost implications may prevent the government of Zambia from utilizing that platform. It is recommended that the national data centre of Zambia is leveraged for data storage and data processing. Since redundancy and resilience are a key factor in national data storage and indeed for the Food Reserve Agency's everyday work. A universal model for a simple and possibly low-cost remote sensor network that may be implemented by the Food Reserve Agency in Zambia was developed and through literature, it is evident that modern warehousing relying on components such as sensors provide better grain storage, management, transparency of operations and hence lead to cost effective grain marketing which leads to better national food security.

5.5. Recommendations

Below are some recommendations for what may be considered stakeholders and enablers of the remote sensor network and IoT revolution.

5.5.1. Deliberate Adoption of the Works by Government

We make a recommendation that the Government of Zambia through the Food

Reserve Agency consider the actual implementation of this work by phased deployment at initially key warehouses and once the concept has proved its researched benefits, to all other locations. This is in trying to further align with the United Nations 2030 Sustainable Development Goals to end Hunger through more effective grain marketing for the sustainable food security of the nation and the word. We also recommend that a study is done on the various systems that the government is deploying to see if they can be unified to prevent unnecessary duplication of efforts. Once e-government is rolled out significantly, it becomes necessary to optimize resources as we have seen from case studies in the United States. It is best to lean from the failures of developed countries and avoid their mistakes. Several resources may be saved and put better use.

5.5.2. Reviewing the Cost of Data

Another recommendation is for telecommunications and internet service providers to deliberately introduce internet of things data plans for subscriber identity module or SIM cards which are the most practical form of communication that a remote sensor network may rely on. Case studies may be carried out as to how such system have worked out elsewhere. Examples of telecommunications companies that are introducing data plans for IoT applications is Deutsche Telekom in cooperation with a company called 1NCE who introduced a 10-year fixed data plan that is a flat rate for one SIM card with 500MB of data for 10 years with no additional cost to 1NCE. With the low data rates but valuable information that an IoT solution can provide, it can be argued that the cost is insignificant but further research is suggested in order to determine the cost and benefits of IoT data plans.

5.6. Future Works

A lot still remains to be done as regards the introduction of ICT's in Zambia's' grain marketing business under the Food Reserve Agency. It must also be pointed out that there are other government agencies that could be brought under the umbrella of the ICT initiatives leading to resource optimization and prevention of the most common problems such as theft and pilferage. Zambia's Farmer Input Support Programme is one other agency that is concerned with the grain marketing business and this could also use research in order to determine the challenges and see if they can benefit from the FRA initiative which has been worked on in this project. It is also believed that the research isn't over as it may require the implementation of a portable working prototype at the FRA warehouses employing our recommended use of the Zambia National Data Centre for data storage and data processing. There is no need for FRA to purchase expensive services when there already exists a tier III NDC. It is also important to dive deeper into the cost implications of the proposed implementation as this research did not go into that. It is recommended that after a recent audit, the cost of the problems be weighed against the cost of the solutions aimed at addressing the problems in order to further determine when the right time to implement might be.

5.6.1. Power Requirements Analysis

A power requirements analysis is the calculated requirement of the power needs of the implementation. In this case, the power requirements analysis defines the minimum needs of the remote sensor network at any particular depot given a certain configuration. As this was not worked on in this project, it is recommended that an automatic calculator is designed that factors in the power requirements of each of the components that would be used on sites and for how long those components would be expected to work for. The output could then be a list of the required power configurations which can further be broken down into battery, grid or a hybrid power solution with cost implications considered.

5.6. Summary

The research has clearly shown that ICTS's could play a major role in streamlining the business processes at the Food Reserve Agency. We have also seen that sustainable food security is a goal that the government of Zambia is working towards, it being a signatory to the United Nations and its 2030 Sustainable Development Goals. Through literature we have also determined that there is evidence that ICT's improve a nation's food security and once a nation has sufficient food for its citizens, this naturally has a spill over effect to the rest of the world. Going by the much researched Maslow's Hierarchy of needs, food is at the base of the physiological needs that govern how well any human being will fair in life(Fallatah & Syed 2018). It is therefore very important that matters related to food security are at the cornerstone of any society and ICT's dramatically improve the food supply chain and value chain system.

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APPENDICES

1. Business Process Modelling Notation Object Reference

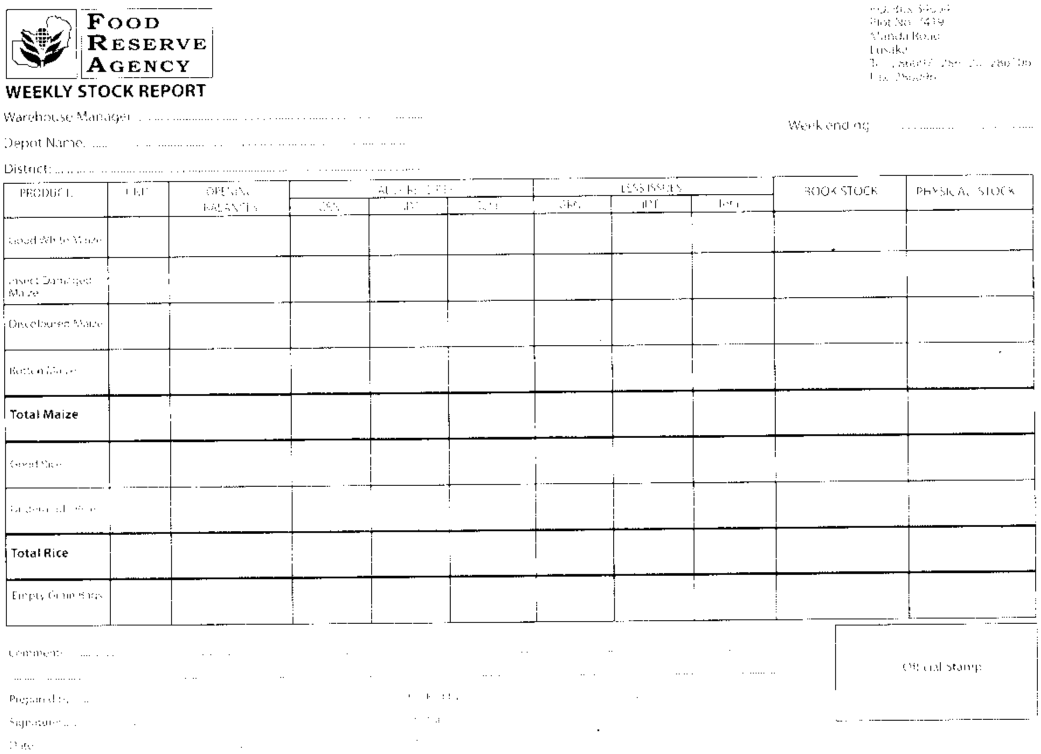
A complete reference of the business process modelling notation business objects can be found on the online resource at https://www.omg.org/spec/BPMN/2.0/.

Object	Name	Description
	Business rule	This is an object that defines a task that depends on input from business rules or regulations. This can normally be implemented or automated by a business rules engine
	Parallel gateway	Indicates that parallel activities or tasks may be performed where used. The activity or task being defined by the association or flow
	Receive	Indicates that something is being received
	Start of process	
	Terminate	

	Event based flow	
	Signal	
	Cancel	
	Escalation	

2. FRA Documents

Several of the FRA documents that were used in order to determine and map the business rules are listed in this section.



FOOD RESERVE AGENCY

WEEKLY STOCK REPORT

Plot No. 7419

Lusaka

Warehouse Manager ....

Week ending ....

Depot Name ....

District ....

PRODUCT	[illegible]	OPENING BALANCES	[illegible]			LESS ISSUES			BOOK STOCK	PHYSICAL STOCK
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Good White Maize										
Insect Damaged Maize										
Discoloured Maize										
Bottom Maize										
Total Maize										
Good Rice										
[illegible] Rice										
Total Rice										
Empty Grain Bags										

Comments ....

Prepared by ....

Signature ....

Date ....

Official Stamp

Figure 46- Weekly stock report

FOOD RESERVE AGENCY

P.O Box 34054
Plot No. 7419
Manda Road, LUSAKA
Tel: +260 211 286097 / 286106 / 286126

Official Stamp.

WEEKLY ISSUES SUMMARY

Warehouse Manager:______________________________

No. 382952

Name of Depot______________________________

Week Ending______________________________

Commodity__________

Date	Particulars	GIN/IDT/IPT No.	Quantity		Cumulative Total	
			(X 50kg bags)	(Metric Tonnes)	(X 50kg bags)	(Metric Tonnes)

Comments: ______________________________

____

Prepared by:______________________ Checked by: ______________________

Signature: Signature:

Figure 47 - Weekly issue summary

FOOD RESERVE AGENCY

P.O Box 34054
Plot No. 7419
Manda Road, LUSAKA
Tel: +260 211 286097 / 286106 / 286126

Official Stamp.

WEEKLY RECEIPT SUMMARY

Warehouse Manager:______________________________ **No.**

Name of Depot______________________________

Week Ending______________________________

Commodity______________

Date	Name of Supplier	PRCN/ GRN No.	Quantity		Cumulative Total	
			(X 50kg bags)	(Metric Tonnes)	(X 50kg bags)	(Metric Tonnes)

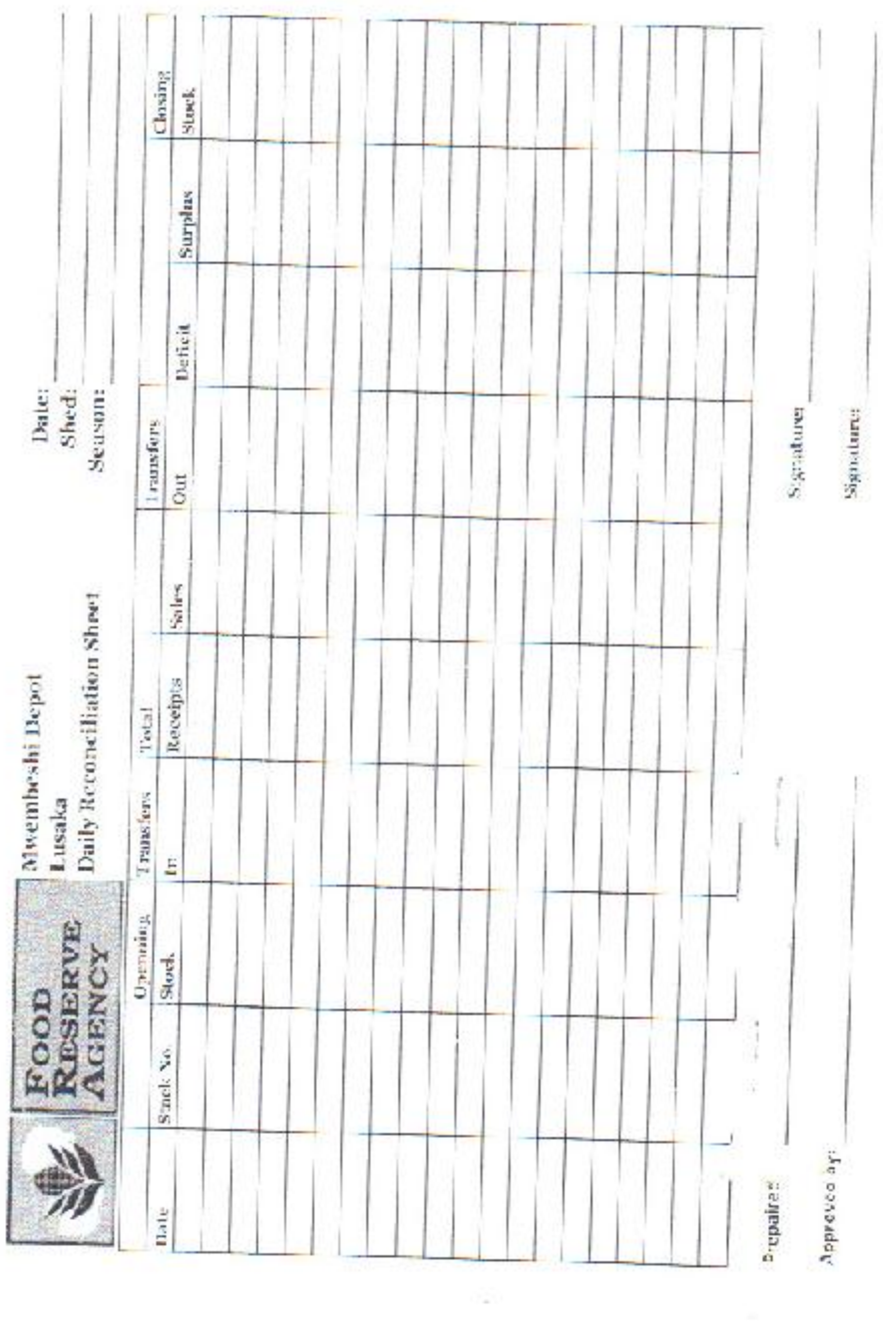
Comments: ______________________________

____

Prepared by:______________________ Checked by: ______________________

Signature: Signature:

Figure 48- Weekly receipt summary



FOOD RESERVE AGENCY

Mwembeshi Depot
Lusaka
Daily Reconciliation Sheet

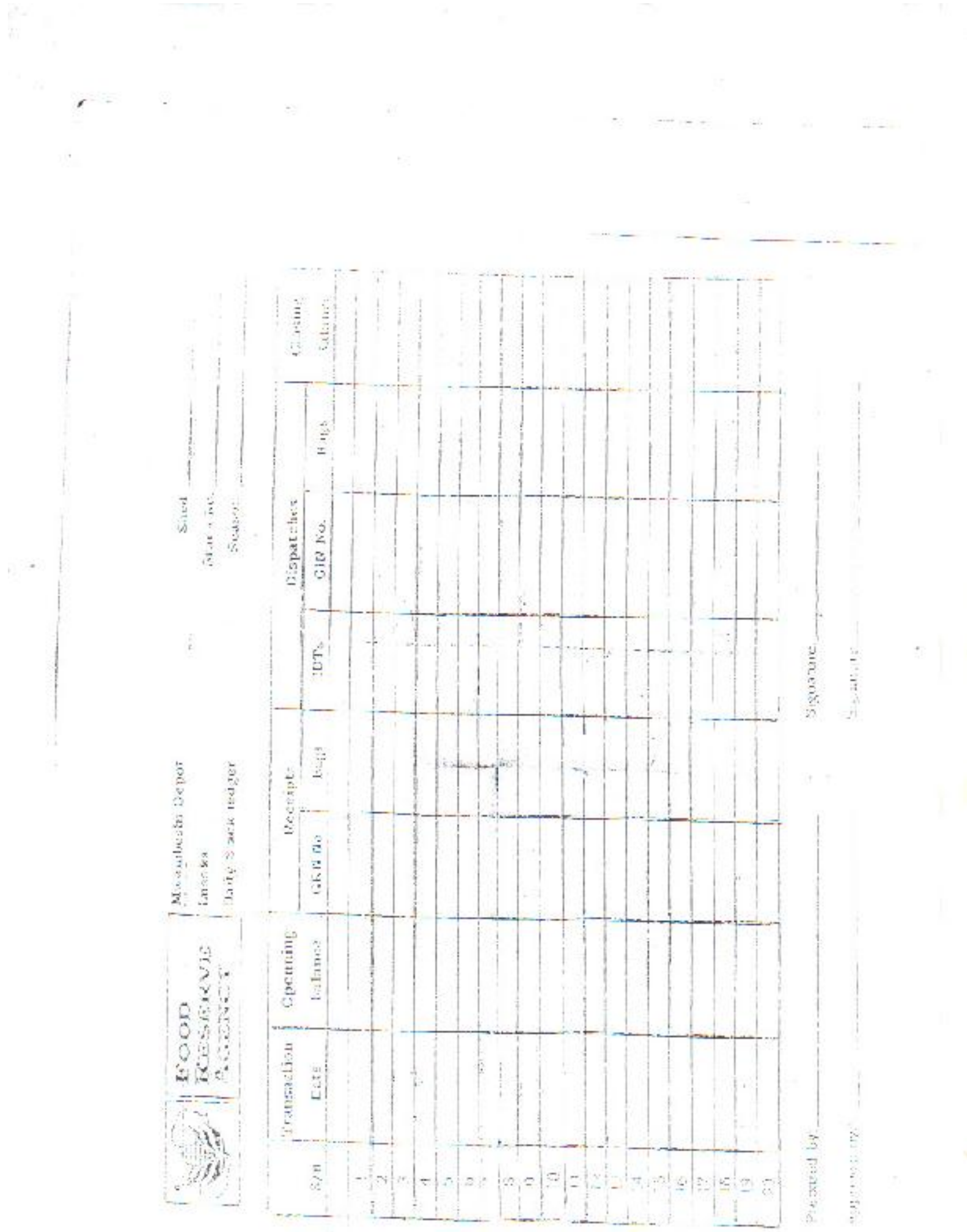
Date:
Shed:
Season:

Date	Stack No.	Opening Stock	Transfers In	Total Receipts	Sales	Transfers Out	Deficit	Surplus	Closing Stock

Prepared by: Signature:

Approved by: Signature:

Figure 49- Daily reconciliation sheet



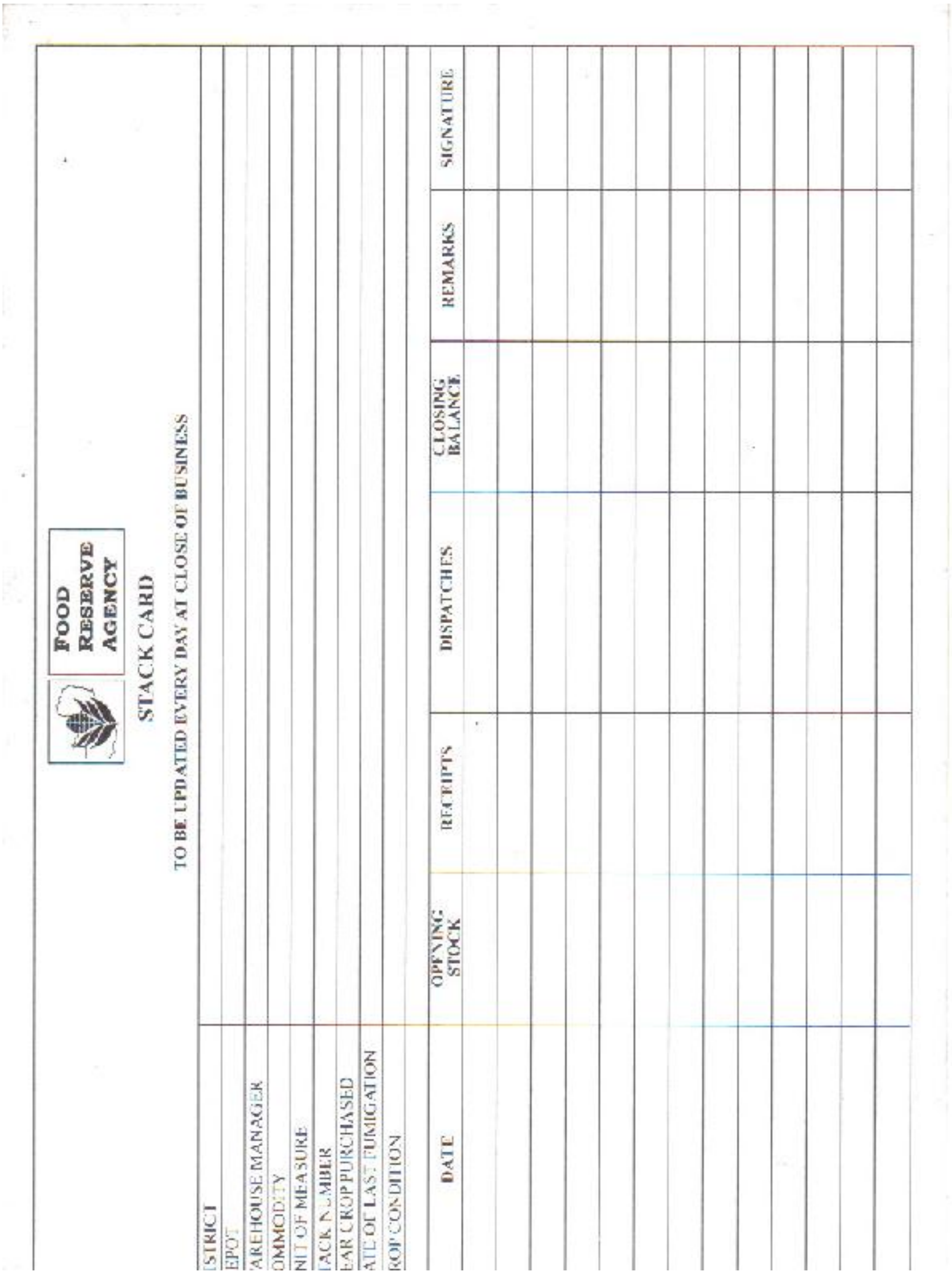
FOOD RESERVE AGENCY

Daily Stack ledger

S/n	Transaction Date	Opening balance	Receipts GRN No	Receipts Bags	Dispatches IDTs	Dispatches GIN No.	Dispatches Bags	Closing balance
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

Prepared by ________ Signature ________

Figure 50 - Daily stack ledger



FOOD RESERVE AGENCY

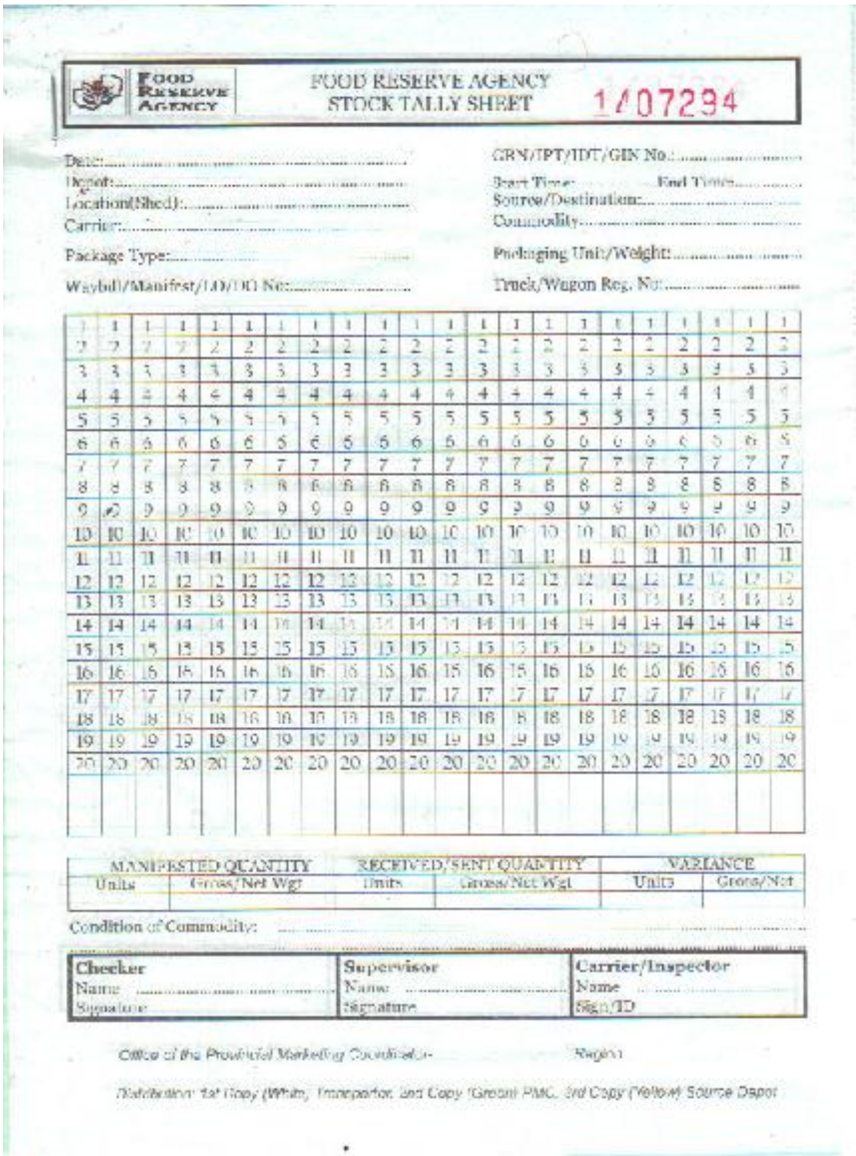
STACK CARD

TO BE UPDATED EVERY DAY AT CLOSE OF BUSINESS

STRICT	
EPOT	
AREHOUSE MANAGER	
OMMODITY	
NIT OF MEASURE	
ACK NUMBER	
EAR CROP PURCHASED	
ATE OF LAST FUMIGATION	
ROP CONDITION	

DATE	OPENING STOCK	RECEIPTS	DISPATCHES	CLOSING BALANCE	REMARKS	SIGNATURE

Figure 51 - Stack Card



FOOD RESERVE AGENCY

FOOD RESERVE AGENCY
STOCK TALLY SHEET 1407294

Date:..
Depot:..
Location(Shed):..
Carrier:..
Package Type:..
Waybill/Manifest/LO/DO No:..

GRN/IPT/IDT/GIN No.:..
Start Time:.................. End Time:..................
Source/Destination:..
Commodity:..
Packaging Unit/Weight:..
Truck/Wagon Reg. No:..

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20

MANIFESTED QUANTITY		RECEIVED/SENT QUANTITY		VARIANCE	
Units	Gross/Net Wgt	Units	Gross/Net Wgt	Units	Gross/Net

Condition of Commodity: ....

Checker	Supervisor	Carrier/Inspector
Name	Name	Name ....
Signature	Signature	Sign/ID ....

Office of the Provincial Marketing Coordinator- .... Region

Distribution: 1st Copy (White) Transporter, 2nd Copy (Green) PMC, 3rd Copy (Yellow) Source Depot

Figure 52- Tally Sheet

FOOD RESERVE AGENCY

Plot No. 7419, Manda Road, Industrial Area
P.O. Box 34054, Lusaka, Zambia
Tel: (260-211) 286097, 286106 & 286113
Fax: (260-211) 286096
E-mail: fra@fra.org.zm / www.fra.orgzm

11th November, 2015

COLLECTION OF DATA FOR THE UNZA – FRA PROJECT

Please be informed that the University of Zambia Department of Computer Science will be collecting data through questionnaires.

They will be visiting FRA Offices in various locations. You are advised to accord them any information that they will require to assist in speeding up the Project that is currently going on.

Please do not hesitate to call the undersigned for any clarifications on mobile 0955 521151.

Kindly be advised accordingly.

Joseph A Phiri

Systems Administrator

WITH REGIONAL OFFICES IN:

CHOMA	CHIPATA	KASAMA	KABWE	NDOLA	LUSAKA	SOLWEZI	MANSA	ISOKA	MONGU
Industrial Area	NAPSA Building	Industrial Area	Industrial Area	Bwana Mkubwa	Industrial Area	Industrial Area	Chembe Road	CIDA Shed	CIDA Shed
CIDA Sheds	P.O. Box 510873	Nared Sheds	Bulangwa Road	Walilang Road	Mwembeshi Rd	CIDA Sheds	Plot No. 287A	P.O. Box 440133	Limulunga Rd
Mwapona Road	Tel: (2162) 21684	Mpika Road	Plot No. 5222	Plot No 3587	Plot No. 7420/17487	Plot No. 110265	P.O. Box 710394	Tel/Fax: (214) 560139	P.O. Box 910255
Plot No. 262		P.O. Box 41031	P.O. Box 80425	P.O. Box 71796	P.O. Box 30034	P.O. Box 110255	Tel: (212) 821061		Tel: (217) 221056

Figure 53 - Data Collection Permission

3. Self-Administered Questionnaire

11/1/2017 QUESTIONNAIRE FOR FRA MANAGEMENT STAFF

QUESTIONNAIRE FOR FRA MANAGEMENT STAFF

Kindly fill in the information below

1. **Role**

2. **Province**
   Mark only one oval.
   - ◯ Lusaka
   - ◯ Central

3. **Zone**

4. **District**

5. **Block**

General

Tick where options are available or provide a brief written explanation.

6. **1. Does the FRA program employ this use of any IT tools?**
   Mark only one oval.
   - ◯ Yes
   - ◯ No
   - ◯ I don't know

7. **2. If yes to the above, which tools are normally used?**
   Tick all that apply.
   - ☐ a. Spreadsheets
   - ☐ b. The Internet
   - ☐ c. Smartphones
   - ☐ I don't know

https://docs.google.com/forms/d/1ogoCFj9uBemjl7nDtKhSeXGHE6a_HwwVezcgNTut7Fw/edit 1/4

Figure 54- Questionnaire page 1

8. **3. Does FRA keep a database of registered suppliers of stock or does FRA buy from anyone with stock?**
Mark only one oval.
- Yes
- No
- I don't know

9. **4. Does FRA purchase stock all year round?**
Mark only one oval.
- Yes
- No
- I don't know

10. **5. Are the current officers in the FRA program well vested in the following IT tools:**
Tick all that apply.
- [ ] a. Spreadsheets
- [ ] b. The Internet
- [ ] c. Smartphones
- [ ] I don't know

11. **6. Are you able to tell the source and destination of products in your supply chain? [ ]**
Mark only one oval.
- 1. YES
- 2. NO
- 3. Don't know

12. **7. With the current FRA supplies and input management system what are the main challenges you encounter in terms of human and administrative matters?**

13. **8. Have you heard of Barcoding and RFID technologies and do you know the differences between the two?**
Mark only one oval.
- A. Yes
- B. No
- C. Don't know

TRACKING

Figure 55- Questionnaire Page 2

14. **9. Will there be any financial challenges/obstacles that would hamper the successful implementation of the tracking technologies?**
Mark only one oval.

- 1. Yes
- 2. No
- 3. Don't know

15. **10. How do you currently keep track of inputs to farmers?**

16. **11. How are transporters monitored?**
Mark only one oval.

- 1. Frequent calls via mobile
- 2. Stopovers at designated location
- 3. There is no monitoring mechanism
- 4. Done know

17. **12. Does stock get distributed to intermediate warehouses before getting to the final destination?**
Mark only one oval.

- 1. Yes
- 2. No
- 3. Don't know

18. **13. If answer is yes to the above, which intermediate warehouses do seeds get distributed to?**

ENVIRONMENT

Figure 56- Questionnaire Page 3

19. **14. What is the critical temperature at which input from farmers may get damaged?**

____
____
____
____
____

20. **15. At what humidity can input from farmers get damaged?**

____

21. **16. Is there currently any monitoring mechanism for environment at which farmers input are kept?**
Mark only one oval.

- 1. Yes
- 2. No
- 3. Don't know

22. **17. Is there currently any monitoring mechanism for the environment at which FRA stock is kept (seeds, fertilizers)? [ ]**
Mark only one oval.

- 1. Yes
- 2. No
- 3. Don't know

23. **21. How is the environment at which farmers input are kept monitored?**
Mark only one oval.

- Hired security firms
- FRA local representatives on site
- Local community representatives
- I don't know

Figure 57- Questionnaire Page 4

4. Consolidated Database ER Diagrams

Figures 68 to 61 show the complete entity relationship diagram for the FRA database that was developed.

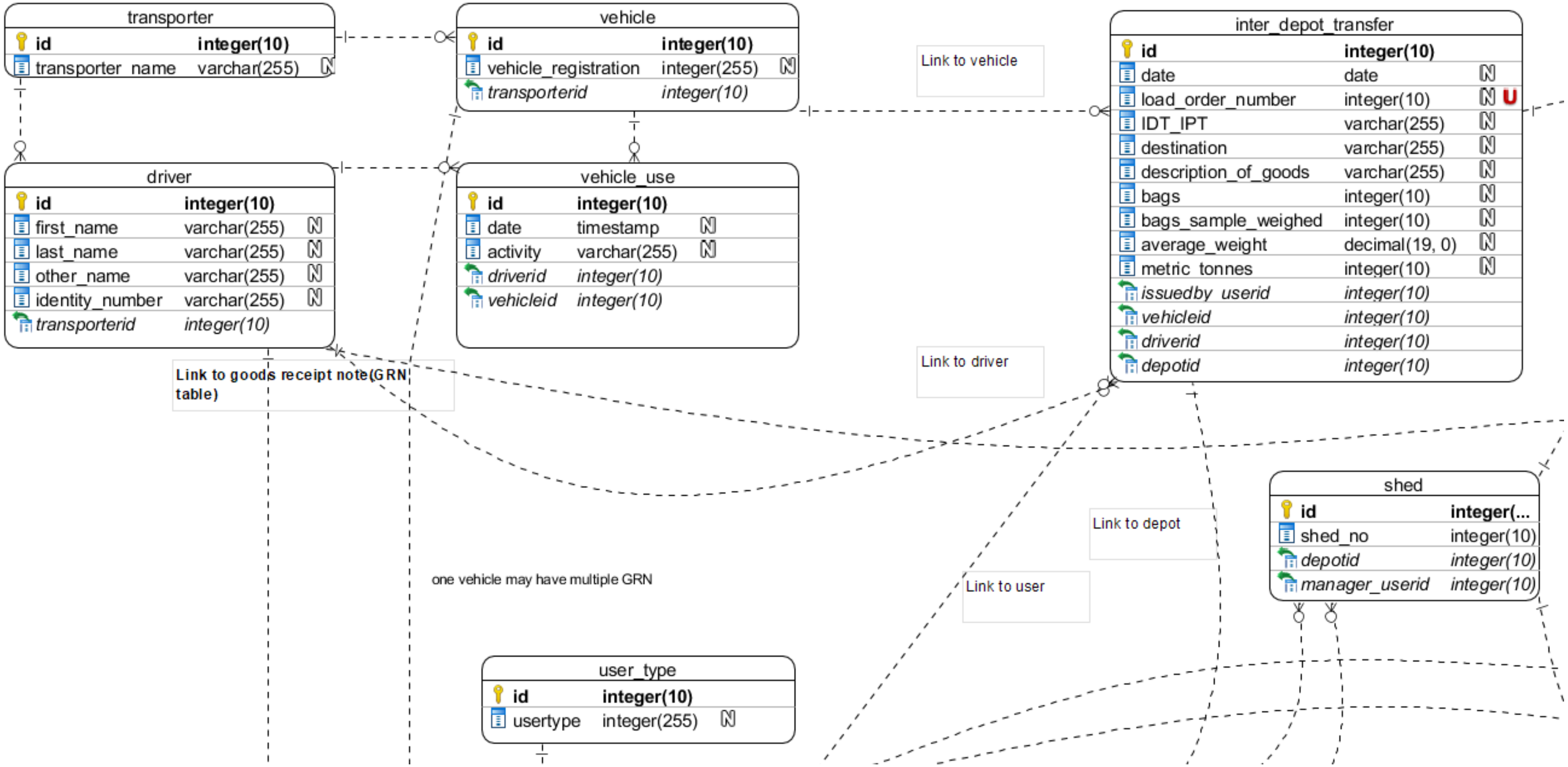


Figure 58 – Consolidated ER diagram of FRA database - 1

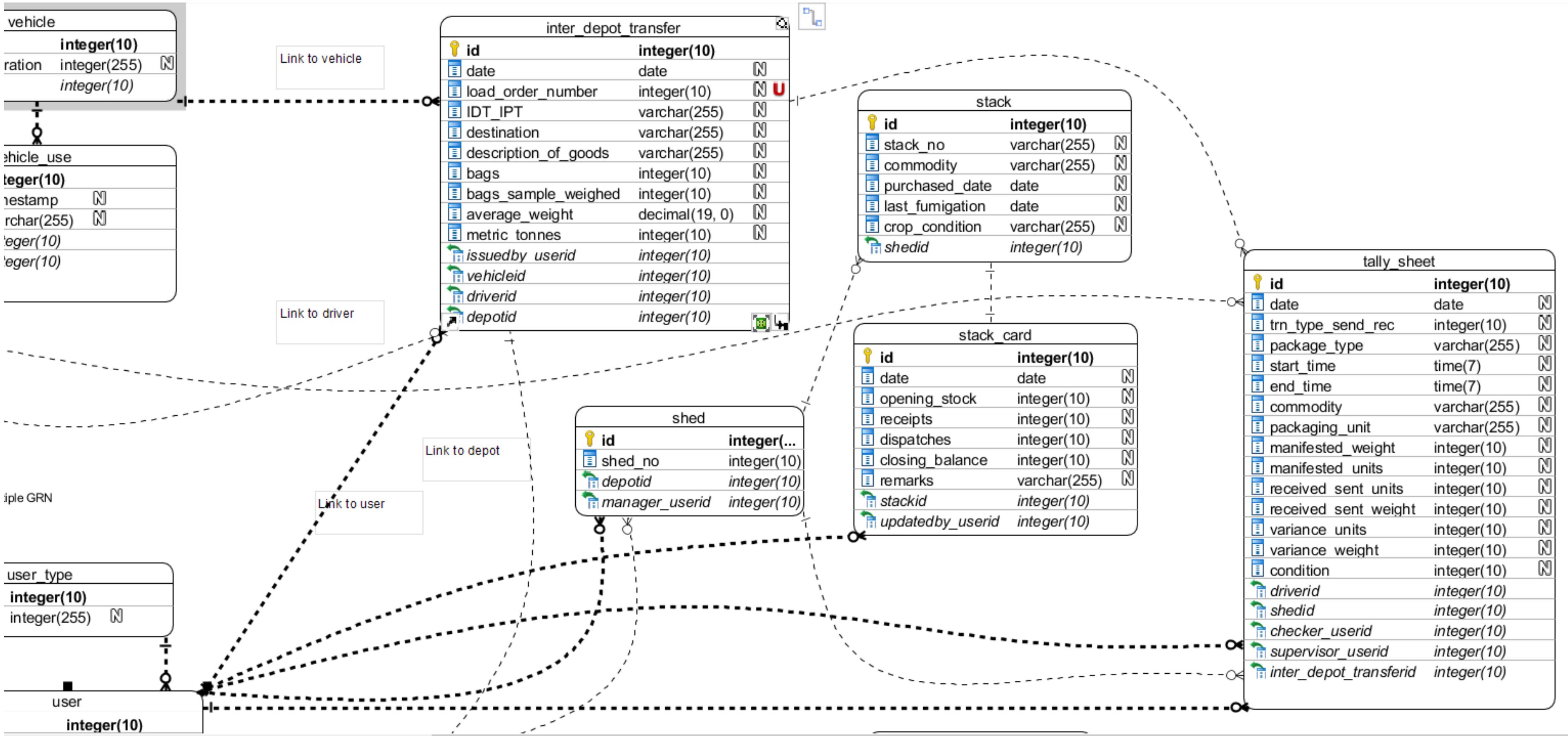


Figure 59- Consolidated ER diagram of FRA database -2

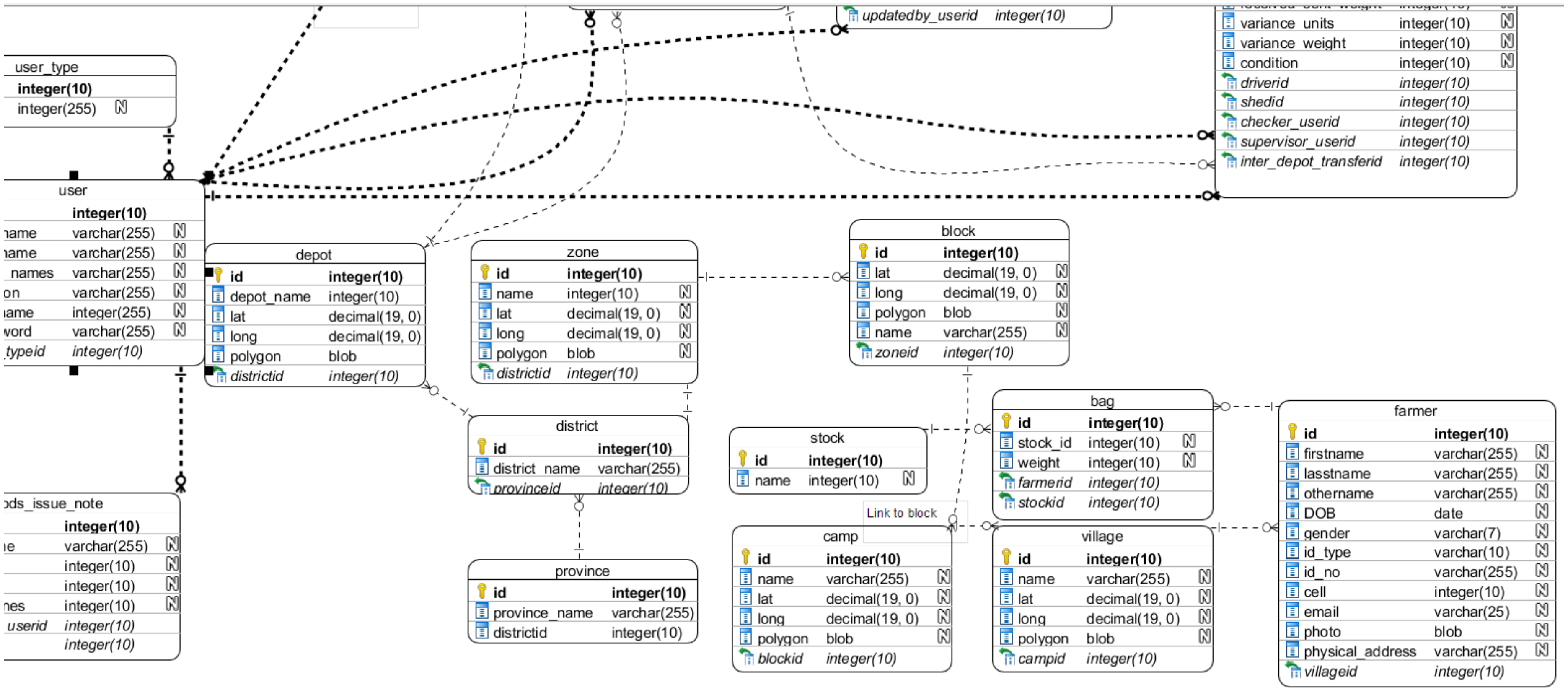


Figure 60- Consolidated ER diagram of FRA database - 3

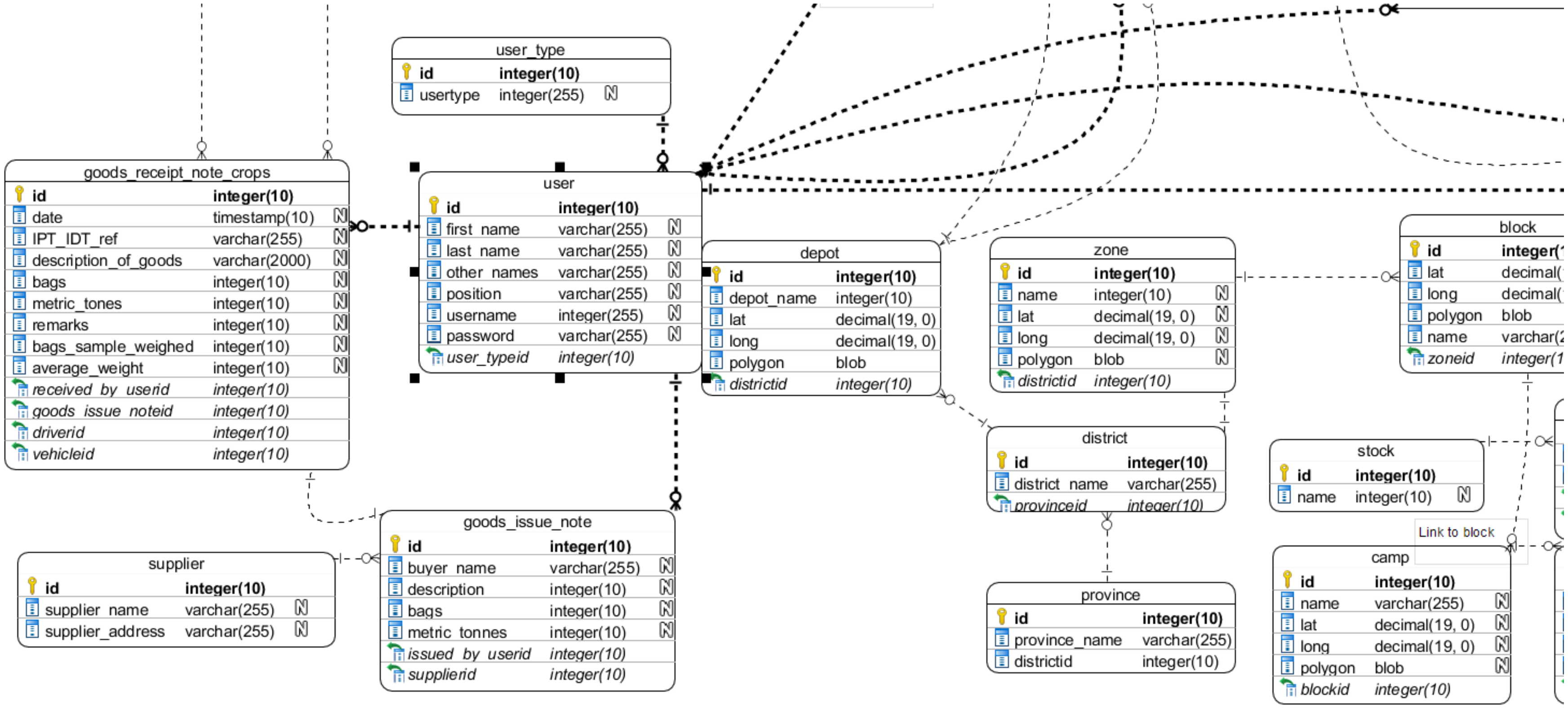


Figure 61- Consolidated ER diagram of FRA database - 4

5. FAO Standards for Grain Storage

Standards for Wheat

Table 9- FAO standards for the storage of wheat

Maximum tolerances (% m/m):	
Foreign or deteriorated odour, additives, toxic substances	0
Pesticide residues, other contaminants	National limit or Codex limit
Living insects	0
Moisture content	15.5*
Bulk density, minimum (kg/hl)	70
Damaged grain	15
of which:	
Broken grain	7
Shrivelled grain	8
Unsound grain	1
Grain attacked by pests	2
Other cereals	3
Extraneous matter	2
Inorganic material	0.5
Harmful and/or toxic seeds, bunted grains and ergot	0.5
Ergot	0.05
Falling number, minimum	160

Standards for Maize

Table 10 - FAO standards for the storage of maize

Maximum tolerances (% m/m):	
Abnormal or foreign odour	0
Moisture content	15.5
Blemished grain	7
of which:	
diseased grain	0.5
Broken kernels	6
Other grains	2
Foreign matter	2

of which:	
inorganic matter	0.5
Filth	0.1
Toxic or noxious seed, heavy metals,	free from
microorganisms or poisonous or	amounts hazardous
deleterious substances	to health

6. RFC1883

Below is a snippet of the IPv6 specification as contained in the RFC1883 specification. For details, please refer to the specification internet home page at https://tools.ietf.org/html/rfc1883. Of Keen interest is the sentence in the introduction part below.

Internet Protocol, Version 6 (IPv6) Specification

Status of this Memo

This document specifies an Internet standards track protocol for the Internet community, and requests discussion and suggestions for improvements. Please refer to the current edition of the "Internet Official Protocol Standards" (STD 1) for the standardization state and status of this protocol. Distribution of this memo is unlimited.

Abstract

This document specifies version 6 of the Internet Protocol (IPv6), also sometimes referred to as IP Next Generation or IPng.

1. Introduction

IP version 6 (IPv6) is a new version of the Internet Protocol, designed as a successor to IP version 4 (IPv4) [RFC-791].