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A novel framework for the use of mobile applications in inducing smallholder-farmers' response to farming as a business via benchmarking

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A NOVEL FRAMEWORK FOR THE USE OF MOBILE APPLICATIONS IN INDUCING SMALLHOLDER-FARMERS' RESPONSE TO FARMING AS A BUSINESS VIA BENCHMARKING

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Information and Communication Science and Engineering of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Farming as a business (FAAB) is currently acknowledged as the best route out of poverty for the majority of rural poor farmers in developing countries like Tanzania. Supporting farmers to participate in FAAB translates into assisting them to go through a farming life cycle of five interrelated stages namely: Agricultural domains recognition, farm characterization, simulation of predictive solutions, identification of limiting factors, and post production evaluation. Managing FAAB processes, resources and products, requires benchmarking as its analytical tool; hence, the concept of farming as a business via benchmarking (FAABB). Supporting a farmer to achieve FAABB is the primary role of an Extension Officer (EO).

Since FAABB is a data-intensive activity, computational and cognitive limitations of an EO decrease quality and efficiency and increase time spent as well as costs related to facilitating smallholder farmers to achieve FAABB. Several research efforts have demonstrated that mobile apps bring in significant capabilities for helping EOs deal with the challenges associated with FAABB.

However, in Tanzania, data capture and codification are the two greater obstacles in developing useful mobile applications, than gaps in conceptual theories or available methods for FAABB. This research takes advantage of available technologies to develop a mobile framework for FAABB that embeds data capture and codification services to support rapid development of domain specific m-apps. The main objective of this research is, therefore, to develop a mobile framework for FAABB (m-FFAABB) that facilitates knowledge capture and codification for rapid development and use of m-apps that induce farmers' response to FAABB.

The research adopted a Design Science Research (DSR) through Soft System Methodology (SSM). In the reported work, the framework was designed and two corresponding prototypes were developed and evaluated to show the applicability of m-FFAABB. The data collected during the experiments show that the mobile apps developed through the m-FFAABB are useful, well integrated and easy to use. Moreover, statistical analysis of the results indicates that the framework reduces time, costs, and intellectual effort of the EOs.

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DECLARATION

I, John Joel Kyaruzi do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this thesis is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

John Joel Kyaruzi

Name and Signature of Candidate

Date

The above declaration is confirmed

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2|08|2021

Date

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5/5/2021

Date

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for the acceptance of the thesis titled *A Novel Framework for the use of Mobile Applications in Inducing Smallholder-Farmers' Response to Farming as a Business via Benchmarking* in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Information and Communication Science and Engineering at the Nelson Mandela African Institution of Science and Technology.

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5/5/2021

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DEDICATION

Dedicated to my mother Zeulia (R.I.P.), my father Joel, my wife Grace, my daughter Jane and my son Victor.

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LIST OF ABREVIATIONS AND SYMBOLS

ABEA	Animal Breading East Africa
AI	Artificial Intelligence
AMCOS	Agriculture Marketing Cooperative Societies
ANSI	American National Standards Institute
API	Application Programing Interface
APISM	Agricultural Production Systems Simulator
ARD	Agricultural and Rural Development
ARM	Action Research Methodology
BMP	Best Management Practices
CATWOE	Customers, Actors, Transformation process, Worldview, Owners and Environmental constraints
CoCSE	Computational and Communication Sciences and Engineering
CoI	Community of Interest
CoP	Community of Practice
CP	Crude Protein
CPA	Chemical Pasture Assessment
CPA	Chemical Pasture Analysis
CREATES	Centre For Research, Agricultural Advancement, Teaching Excellence and Sustainability
CSA	Chemical Soil Analysis
DDIS	Distance Diagnostic and Identification System.
DM	Dry Matter
DSL	Digital Subscriber Line
DSR	Design Science Research
DSS	Decision support systems
DSSAT	Decision Support System for Agro technology Transfer
EDIS	Electronic Data Information Source
EFS	Economic Farm Surplus
EFS/ha	Economic Farm Surplus Per Hector
EO	Extension Officer
FAAB	Farming As A Business
FAABB	Farming As A Business Via Benchmarking
FAO	Food and Agriculture Organization of the United Nations

FAWN	Florida Automated Weather Network
FLSART	Florida State Agricultural Response Team
FSI	Farm Sustainability Index
GEG	Grassroots Economic Group
GIS	Geographic information system
GPRS	General Packet Radio Service
HPC	High Performance Computer
HTTP	Hypertext Transfer Protocol
IBM	International Business Machines Corporation
ICSE	Information and Communication Science and Engineering
ICT	Information and Communication Technology
ILRI	International Livestock Research Institute
IoT	Internet of Things
IP	Internet Protocol
IS	Information System
ISO	International Organization for Standardization
IT	Information Technology
JSON	Javascript Object Notation
KIBS	Knowledge-Intensive Business Services
KPIs	Key Performance Indicators
LiSBE	Life Science and Bio-Engineering
M	Median
MAFSC	Ministry of Agriculture, Food Security and Cooperatives
m-ARD	Mobile Information Systems for Agricultural and Rural Development
ME	Metabolisable Energy
m-FFAABB	Mobile Framework for Farming As A Business Via Benchmarking
NDF	Neutral Detergent Fibre
NM-AIST	Nelson Mandela African Institution of Science and Technology
NoSQL	Not only Structured Query Language
NPDN	National Plant Diagnostic Network
PTM	Prototyping Methodology
RDBMS	Relational Database Management Systems
REST	Representational State Transfer
SaaS	Software-as-a-Service
SAGCOT	Southern Agricultural Growth Corridor of Tanzania

SAGCOT	The Southern Agricultural Growth Corridor of Tanzania Catalytic Trust
CTF	Fund
SDTK	Software Development Tool Kit
slPests	Southeast Landscape Pest
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SQL	Structured Query Language.
SRUC	Scotland's Rural College
SSM	Soft System Methodology
SUS	System Usability Scale
TCT	Task Completion Time
UF/IFA	University of Florida's Institute of Food and Agricultural Sciences
UI	User Interface
URI	Universal Resource Identifiers
URL	Uniform Resource Locator
VPA	Visual Pasture Assessment
VPN	Virtual Private Network
VSA	Visual Soil Assessment
WiMAX	Worldwide Interoperability for Microwave Access
WOA	Web Oriented Architecture
XML	Extensible Markup Language
3G	Third generation of wireless mobile telecommunications technology

CHAPTER ONE

INTRODUCTION

1.1   Background of the Problem

Farming as a business (FAAB) is currently acknowledged as the best route out of poverty for the majority of rural poor farmers in developing countries like Tanzania. Supporting farmers to participate in FAAB translates into assisting them to increase productivity, through both quality and quantity enhancements. The assistance means helping them to have many support services including proper choices of farms, administration and monitoring of inputs and extension services provided to these farms, postharvest handling, market choices, etc. It is a primary role of Extension Officer (EO) to support and assist a farmer to achieve FAAB (Rwebangira, 2017).

Farmers face quite a number of challenges in conducting FAAB. Challenges emanate not only from deficits or unavailability of EOs (Ministry of Agriculture, Food Security and Cooperatives [MAFSC], 2011), but also from poor farm services and management, which limit farmers' uptake of many viable business opportunities. However, even where EOs are available, often they have poor knowledge and information to assist farmers. For example, while EOs are expected to be the primary backstopping agents for farmers in bridging information and knowledge gaps, it has been observed that most EOs are assigned to subsectors for which their understanding of domain is handicapped (International Livestock Research Institute, & Scotland's Rural College [ILRI & SRUC], 2014). In some cases, one EO serves farmers engaged in multiple subsectors, whose workings is ill informed about (Lwoga *et al.*, 2010).

Supporting smallholder farmers to increase productivity requires a lot of data, information and knowledge necessary to undertake proper choices and decision for farm identification, registration, facilitation and monitoring of extension services provided to their farms (Poulton *et al.*, 2010). A practical and formal way of realizing FAAB is through Benchmarking, hence the concept of "Farming as a Business via Benchmarking (FAABB)" (Kahan, 2010). The FAABB is a formal process for EOs to engage smallholder farmers to improve their farm performance, for the purpose of achieving productivity and profitability, which require a better understanding of both the business and technical aspects of farming.

At farm-level, "benchmarking" is conducted by an EO who plays the role of farm manager on behalf of a group of farmers, each organized as a "grassroots economic group" (GEG), and

uses benchmarking techniques to identify problems that prevent the block farm of the GEG from achieving its full value and devise means to improve (Kahan, 2010).

Various models have been developed in the literature in order to describe FAABB business logic (Antonopoulos *et al*., 2014). The Crop modeling (Dodds *et al.,* 2019; Dury *et al.,* 2012; Jones *et al.,* 2017a) and dairy modeling (Gichamba & Lukandu, 2012; Tedeschi *et al.,* 2014) are some of the grand references of the FAABB modeling. All these models have highlighted the FAABB decision process, which covers the entire farming business lifecycle in five stages. These stages are the domain recognition, product characterization, farm production, limiting factors control, and post-production evaluation (Boote *et al.,* 2015; Van Ittersum *et al.,* 2013). Although mobile information systems provide potentials and significant capabilities to address challenges of EOs in the FAABB decision process, to the best of our knowledge and according to a recent research study, there is currently no study exploring a holistic approach to support EOs in all stages of the FAABB (Kyaruzi *et al*., 2019b). Common limitations across all systems, include a) scarcity of data for modelling, evaluating, and applying benchmarking and b) inadequate knowledge systems that effectively communicate benchmarking results to EOs. These two limitations are greater obstacles to developing useful mobile applications than gaps in conceptual theory or available methods for using FAABB (Kyaruzi *et al*., 2019a).

Knowledge and information deficits, therefore, adds-on as a critical constraint for enabling FAABB through mobile technologies. One of the main obstacles is collecting the required data at each stage of the process. For example, during product characterization stage, information on soil properties and plant characteristics are essentials that EOs do not typically acquire online to assist their farmers. Instead, EOs rely on their personal experiences and end up guessing. One would expect that a practical FAABB approach to address this challenge is by enabling collection of the required data through the contributions of EOs, and allowing them to gather, use and share information collected through their mobile devices (Greenberg, 1997).

This research is focused on investigating EOs' challenges in their FAABB activities by examining literature, and addressing these challenges through the use of mobile technologies. Specifically, designing a mobile framework that supports a systematic data capture and knowledge codification to support FAABB. Accordingly, this research borrows principles and concepts from a design science research domain to develop such a framework.

1.2 Statement of the Problem

Farmers face quite a number of challenges in conducting farming as a business (FAAB). Challenges emanate not only from deficits or unavailability of Extension Officer (MAFSC, 2011), but also from poor farm services and management, which limit farmers' uptake of many viable business opportunities. However, even where EOs are available, often they have poor knowledge and information to assist farmers (ILRI & SRUC, 2014; Lwoga *et al.,* 2010). Although mobile information systems provide potentials and significant capabilities to address challenges of EOs in the FAABB decision process, to the best of our knowledge and according to a recent research study, there is currently no study exploring a holistic approach to support EOs in all stages of the FAABB (Kyaruzi *et al*., 2019b). Common limitations across all systems include: (a) Scarcity of data for modelling, evaluating, and applying benchmarking, and (b) Inadequate knowledge systems that effectively communicate benchmarking results to EOs. These two limitations are greater obstacles to developing useful mobile applications than gaps in conceptual theory or available methods for using FAABB (Kyaruzi *et al*., 2019a). Therefore, this research is focused on investigating EOs' challenges in their FAABB activities and addressing these challenges through designing a mobile framework that supports a systematic data capture and knowledge codification to support FAABB. Accordingly, this research borrows principles and concepts from a design science research domain to develop such a framework.

1.3 Rationale of the Study

Farming as a business (FAAB) is currently acknowledged as the best route out of poverty for the majority of rural poor farmers in developing countries like Tanzania. Supporting farmers to participate in FAAB translates into assisting them to increase productivity, through both quality and quantity enhancements. Supporting smallholder farmers to increase productivity requires a lot of data, information and knowledge necessary to undertake proper choices and decision for farm identification, registration, facilitation and monitoring of extension services provided to their farms (Poulton *et al*., 2010). A practical and formal way of realizing FAAB is through Benchmarking, hence the concept of "Farming as a Business via Benchmarking (FAABB)" (Kahan, 2010). The FAABB is a formal process for EOs to engage smallholder farmers to improve their farm performance, for the purpose of achieving productivity and profitability, which require a better understanding of both the business and technical aspects of farming. Through benchmarking data capture and knowledge codification, m-FFAABB is

intended to become a holistic and extensible solution to assist EOs in all stages of the FAABB decision process.

1.4 Research Objectives

1.4.1 General Objective

To propose a mobile framework for FAABB (m-FFAABB) to address the challenges of EOs by complementing the FAABB stages with unified data capture and knowledge codification approach.

1.4.2 Specific Objectives

The objectives of this work were, therefore, threefold:

(i)   To define a framework of critical value chain actors, their functions, and optimal orientation that facilitate the management of each stage of the FAABB process.

(ii)   To develop a decision support framework (providing basic services), that facilitates EOs to conduct guided FAABB electronically.

(iii)   To develop a knowledge capture and codification framework to ensure that FAABB data is available for mobile application developers for addressing a wide range of use-cases.

1.5 Research Questions

(i)   How is the framework of critical value chain actors, their functions, and optimal orientation that facilitate the management of each stage of the FAABB process is going to be defined?

(ii)   How is the decision support framework (providing basic services), that facilitates EOs to conduct guided FAABB electronically is going to be achieved?

(iii)   How is the knowledge capture and codification framework to ensure that FAABB data is available, as an external service for mobile application developers for addressing a wide range of use-cases is going to be achieved?

1.6   Significance of the Study

There are three main contributions of this research into the body of scientific knowledge, these are further explained as follows:

(i)   The primary contribution of this research is the framework as an artifact; the Mobile Framework for Farming As A Business Via Benchmarking (the m-FFAABB Business Logic). Consistent with recent research studies (Kyaruzi *et al.*, 2019b), m-FFAABB is an integrated and holistic framework that contributes to the body of knowledge in the area of Agricultural and Rural Development (ARD) systems. This framework includes the facilitating components that assist each stage of the FAAB decision process and benchmarking framework that integrates and coordinates the process components. According to the results of the evaluation the mobile apps developed based on the proposed framework *reduces intellectual effort, time and cost, and increases the quality of the decisions by EOs*.

(ii)   The developed m-FFAABB API for External Benchmarking Services is a key issue to assist mobile application developers to have an Application Programing Interface (API) that provides an easy way of exchanging external data and information for undertaking external benchmarking through mobile apps for specific use-cases. Based on Javascript Object Notation (JSON) data format, this solution provides seamless data exchange solution between m-FFAABB servers at Centre For Research, Agricultural Advancement, Teaching Excellence and Sustainability (CREATES) and the mobile apps developers, and eliminates errors in the extraction of information. A Representational State Transfer Application Programing Interface (RESTful API) based on JSON data formats is developed as a demonstration of its typical use.

(iii)   In addition to the design of m-FFAABB, two prototypes were implemented to demonstrate the applicability of the proposed framework in the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) areas. According to Hevner *et al.* (2004), as an instantiation of the primary artifact, the prototype implementation is also a contribution. In addition, experiments were carried out on the prototype in order to evaluate the functionality as well as the usability aspects of the framework.

1.7 Delineation of the Study

This research is focused on investigating EOs' challenges in their FAABB activities by examining literature, and addressing these challenges through the use of mobile technologies. Specifically, designing a mobile framework that supports a systematic data capture and knowledge codification to support FAABB. Accordingly, this research borrows principles and concepts from a design science research domain to develop such a framework.

CHAPTER TWO

LITERATURE REVIEW

2.1   Farming as a Business Stages

Researchers have developed different models in order to explain the farming behavior (Dury *et al.,* 2012; Jones *et al.,* 2017a). According to the common ground of these models, the five-stage farming decision process includes (a) the domain recognition, (b) product characterization, (c) farm management, (d) limiting factors control, and (e) post-production evaluation (Antle *et al.,* 2017; Kyaruzi *et al.,* 2019; Jebaraj & Sathiaseelan, 2017). Figure 1 depicts the framework for FAABB as advocated in literature (Kyaruzi *et al*., 2019b).
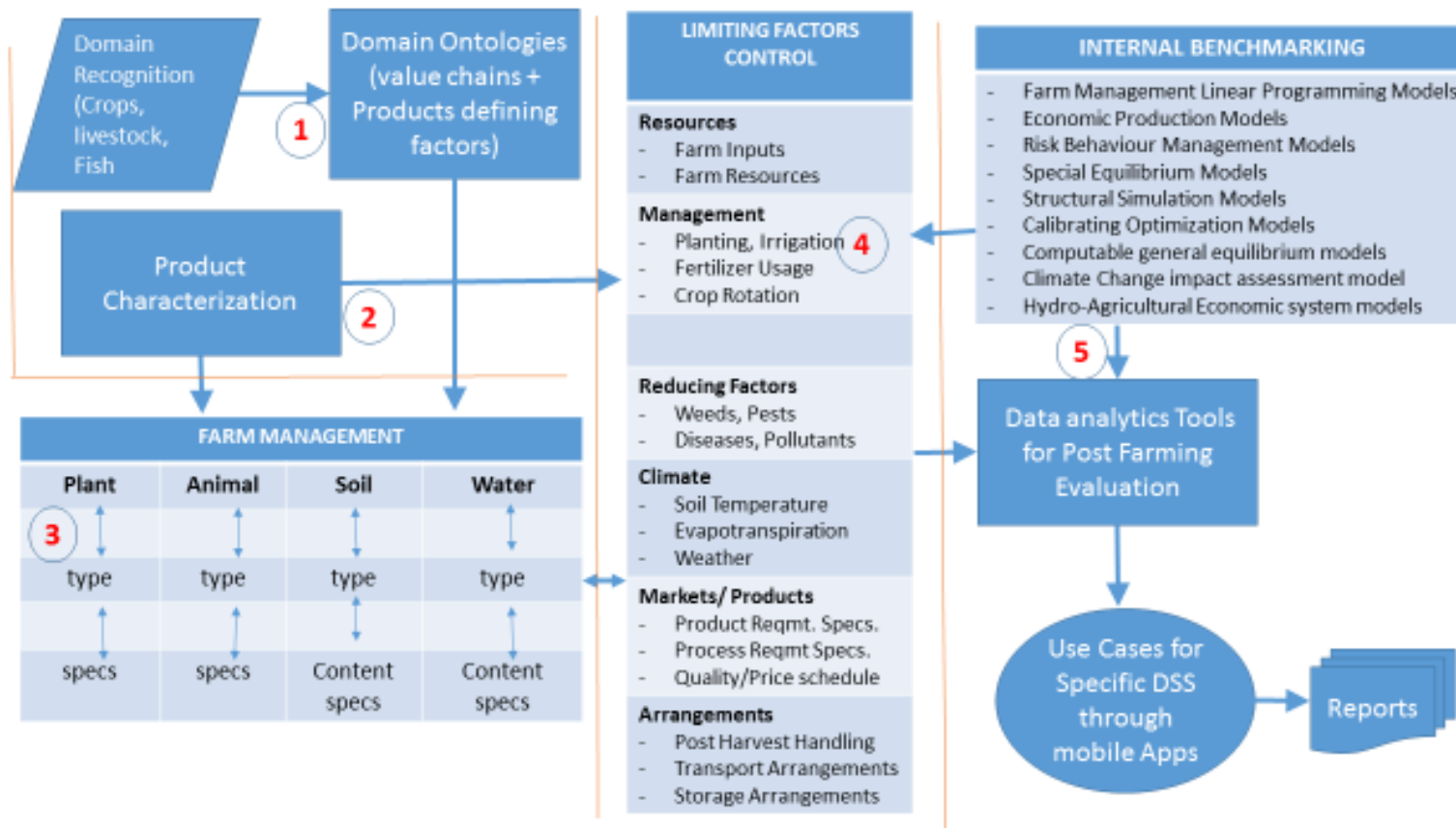
Figure 1: The Farming as a Business via Benchmarking Framework (Kyaruzi _et al._, 2019a)

The FAAB is concerned not only with the 'bottom line' of farmers making money but also technical aspects of farming that contribute to making the farm business profitable and efficient. Improving the performance of the farm business requires a good understanding of both the business and technical aspects of farming (Kahan, 2010).

Benchmarking is a concept that is used to analyze and better understand the farm as a business. To do this, benchmarking is conducted by an EO in a way similar to a doctor diagnosing the condition of a patient. Diagnosing performance means understanding business concepts such as profitability and efficiency, identifying the problems that prevent the farm from achieving its potential and formulating strategies and actions to improve its business performance. Table 1 summarizes EOs' benchmarking activities and EOs' challenges in each stage of the FAAB decision process. These challenges were obtained through a series of stakeholders' meetings that were organized by SAGCOT Catalytic Trust Fund.

Table 1: Extension Officers' Activities and Challenges in each Stage of the Farming as a Business Process

FAAB Stage	Benchmarking Activities	EO Challenges
1. Domain Recognition	Use the industry's best practices to identify Agro sub-sector (e.g., crop, fisheries, livestock, forestry, etc.) and define critical value chain actors	Limited knowledge of the domain and its critical value chains
	Use available markets requirements to establish the basic product characteristics (e.g. milk, maize, tuner fish, meet, flower, etc.)	Limited awareness of the available market requirements.
2. Product Characterization	Use neighboring/similar best producing farms as a basis for configuration (e.g., farm size, alternate crops, critical events)	Limited knowledge for Mapping best practice for production
	Identify farm blocks that meet the minimum requirements and manage GEG	Limited benchmark farm data
	Identify and managing critical events and role players during production.	Information overload
3. Farm Management	Obtain benchmarks for managing farm waste, soil, nutrients, grass grazing, animal husbandry, irrigation, etc. Determine the measurement/ evaluative criteria and decide alternatives to evaluate	Limited capacity of the EO's memory to consider multiple alternatives
	Value the performances of the production alternatives	Limited technical capacity to select the proper seedling, soil and water contents
4. Limiting Factors Control	Use vendors and input suppliers to determine resources available	Limited information on local environmental constraints
	Use external organizations to establish environmental constraints,	
	Determine best farm management practices	Limited Modeling capacity
	Evaluate markets and logistical restrictions	Lack of technical assistance
5. Post-Production Evaluation	Compute product quality levels attained	Minimal Sharing post-production results with related stakeholders
	Analyze resources invested versus utilization	
	Compute sales and profit margins,	Limited modeling capacity
	Compute relative production to similar farms/farmer groups	Limited computational capacity
	Compute the economic benefits	

2.1.1   The Domain Recognition Stage

Domain recognition is the difference between the market's desired (ideal) product requirements and the actual farm situation for its production. In the domain recognition stage, the EO identifies a product, recognizes its defining factors for its production, and becomes motivated to engage farmers for its production for the purposes of making money. The markets themselves or the industry or national priorities can trigger the domain knowledge recognition.

The defining factors for production are intended to codify the standard properties of the target produce and the ideal environmental conditions for its production. These factors predict crop/herd growth and yield at farm level and are typically obtained by narrowing down the many factors that are needed to estimate full potential production. For example, potential crop production is determined by defining factors of CO_2, radiation, temperature, and crop characteristics (Wit *et al*., 2019). The domain recognition also requires knowledge of all intermediate role players in the value chain and their preferences.

In this stage, an EO identifies the required product specie after encountering a need from farmers or markets, but they may fail to prescribe the needed seedlings, inputs required and even best production seasons because of the limited knowledge of the product species under consideration (World Bank, 2010). In this case, value chain ontologies and their studies are basic tools to understand and recognize the domain.

The outcome of the domain recognition stage is an intention to farm: farm or do not farm. Once EOs evaluate the alternatives, they decide a particular product and brand in the second stage of the FAAB decision process. The EOs face greater challenges in acquisition of knowledge to understand the critical aspects of the value chains before convincing smallholder farmers to make the commitment to farm (Niles *et al.*, 2015).

2.1.2   The Product Characterization Stage

After an awareness of the domain has been built, the farming passes to the second stage; information search for product characterization. This stage is also described as the acquisition of information from the environment (Dodds *et al*., 2019). Farm characterization include capturing data regarding the farm's specific characteristics that qualify specific produce in a specific farm location. Farm characterization also captures alternate crops rotation and production dependences for higher productivity/gains.

The available information on farm (whether real or hypothetical), simulated or based on previous seasons records, serve as a demonstration of how the farm should be characterized. It can be studied, learned from and copied. In some cases, there could even be a number of benchmark farms selected for comparison. Because of the nature of smallholder farmers and their farm sizes, farm characterization also involve managing farmers in a group to achieve farming scales. It also includes managing quite a number of critical events at the farm level on how to live with a crop or an animal.

The EOs face greater cognitive challenges in environments with higher levels of information. The EOs are faced by information overload, and a vast amount of parameters to consider since a typical farm includes more than 30 parameters (Ban, 2004).

2.1.3   The Farm Management Stage

Once the EO evaluates production alternatives in stage two and makes a choice, it is time to turn them into management realities. According to Owens *et al.* (2003), EOs need to understand and apply the concepts of profitability, technical efficiency and economic efficiency as they relate to the farm business. Further, the relationships between inputs, costs, outputs and income need to be understood. At its basic level, farm production is a function of: (a) Soil structure and content, (b) Plant/pasture seedling type and its properties, (c) The Animal/herd type and its properties, and (d) Water availability and its contents.

For example, maintaining good soil quality is critical for resource-efficient farming. Soil itself is a resource, so its degradation represents one component of resource inefficiency. But fundamentally, soil degradation leads directly to inefficient use of other resources, such as fertilizers in agricultural production, and damage to surrounding environmental resources including water bodies (Antonopoulos *et al.*, 2014). The EOs face challenges of technical analysis as well as managing procurements of inputs and service providers when the appropriate funds are available.

2.1.4   The Limiting Factors Control Stage

Limiting factors are formalized as constraints on the production alternatives that restrict the selected farm from reaching its full potential. For example, water-limited and/or nutrient-limited production constrain the farm from achieving full growth potential. Other limiting factors include farm resource availability, climate, market requirements, etc (Van Ittersum *et al*., 2013).

According to Kyaruzi *et al*. (2019b) usually this stage has the most influence for decision making regarding the evaluative criteria. The EOs make at least six farm constraint modeling to decide on whether to farm or not to farm. These are market brand requirements, required services and their providers, market analysis to determine quantity required, timing and logistics, funding requirements and potential sources of funds, and environmental effects and climatic constraints. Frequently, EOs struggle to undertake such analysis.

Unfortunately, funding is the dominant challenging factor for EOs since mitigation of most of the limiting factors requires financing to pay for the service provider for their resolution (Mpandeli & Maponya, 2014). Existing market-driven financing models that have inbuilt loyalty programs and/or government-subsidized interventions remain a challenge for EOs to undertake because of their demand for technical financial knowledge.

2.1.5 The Post-Production Evaluation Stage

Post-production evaluation is the final stage, where EOs evaluate whether they are satisfied or dissatisfied with the farm production. After production or harvest, EOs begin to evaluate the performance of the farm in the process. The outcome of the evaluation is efficacy and productivity satisfaction or dissatisfaction. It relies on the relationship between expectations of the farmers (as simulated at stage 2) and perceived performance of the farms (by their markets as realized at stage 4). According to Kahan (2010), if the production meets expectations, the FAAB is achieved; otherwise, the FAAB is not achieved. In addition, post-farming evaluation determines whether the EO makes a complaint, convinces farmers to invest on the production again, and talks favorably or unfavorably about the product with other EOs.

The critical challenge for EOs at this stage is the acquisition of information on sales and computing their relationship to quite a numbers of production variables and stage basic reports on issues like profitability, economic value, resource utilization, etc. Again, these are necessary reports that provide leads to whether or not to engage in farming this product in the next farming cycle.

2.2   Supporting Extension Officers to Achieve Farming as a Business

2.2.1   Extension Officers' Challenges in Supporting Farming as a Business

As a direct conclusion of Section 2.1, EOs faces quite a number of challenges in facilitating FAAB decision process. In Tanzania, in particular, most EOs suffer from knowledge and information deficits (Simba & Yonah, 2014) e.g. about good farming practices, the benefits of using improved breeds/seed, market prices for their outputs, etc. The insufficient number of experienced EOs engaged in agriculture in general (Rwebangira, 2017) and the crops (Belay & Abebaw, 2004), fishing (Njera *et al*., 2016), and livestock (Nell *et al.*, 2014) subsectors in particular, in part, reflect the reality that there has been very little investment on knowledge codification in the sector.   Lwoga *et al.* (2010) summarizes these problems, as explained below:

(i)   Unavailability of Public Extension Officers

Most of the surveyed communities either lacked EOs or they had only a few EOs to assist them when they had problems. Further, most EOs were ignorant about indigenous farming techniques, and thus farmers were reluctant to seek information from them.

(ii)   Lack of Awareness of Information Sources

Farmers, once they had a problem, were not aware of their right to consult formal sources of knowledge, such as EOs or district officers through their village leaders. Thus, most of them depended on the informal sources of knowledge such as family, neighbors and friends, who at times were not sufficiently knowledgeable or reliable to solve their problems.

(iii)   Location

Concerns were raised about the long distance that farmers had to travel to consult the EOs at their stations or to negotiate prices with middlemen.

(iv)   Socio-economic and Social Factors

Socio-economic status and age limited some farmers to seek knowledge from their fellow farmers, farmer groups, village authorities and EOs. For instance, farmers reported that they were too old to seek information from the various sources that existed within and outside their villages.

(v)   Inability of Some Experts to Solve Problems

Some farmers were discouraged from seeking information and knowledge from within and outside their villages because some of that knowledge was not effective in solving their problems.

(vi)   Selfishness

Some farmers were selfish about sharing their knowledge, which limited other farmers in seeking knowledge and information.

(vii)   Nature of Small-Scale Farming

Most farmers felt that there was no need to seek information and knowledge to solve their farming problems because they farmed on a small scale.

The knowledge and information deficits act as a critical constraint on achieving improvements in smallholder farmer productivity and Agricultural and Rural Development (ARD). Furthermore, decision making process in small scale farming is challenged by the amount of the effort spent for the decision making. These two challenges exist in all farming practices involving smallholder farmers in the developing countries (Kyaruzi *et al*., 2019a). Addressing these challenges requires both analytical as well as knowledge codification tools.

2.2.2   Benchmarking as an Analytical Tool for Farming as a Business

Benchmarking as an analytical tool has many definitions (Jetmarová, 2012): (a) The search for organizations best practices that lead to superior performance, (b) A continuous and systematic process of evaluating organizations recognized as leaders by their peers by determining business and work processes that represent best practices and establishing rational performance goals, and (c) Measurement through comparison, identification of best practices, implementation through adaptation, continuous improvement and systematic process in carrying out analytical activity. Therefore, these areas include relevant aspects of any benchmarking process.

In FAAB, the term 'benchmarking' is used to cover a number of practices found in farming that are designed to highlight the good and make it possible to avoid the harmful. Benchmarking is a process of identifying, learning from and adapting good practices and processes to help improve performance (Kahan, 2010). According to Kahan (2010)

benchmarking can be informal or formal, internal or external as expounded in the following paragraphs:

(i)   Informal Benchmarking

Traditionally, farmers often do benchmark informally. For example, a farmer sees another farmer with a larger harvest or one who gets a better price for the same product at the same market. By observing and talking to successful farmers, others can learn how to improve the performance of their farms. Informal benchmarking can result from something as straightforward as a walk around someone else's farm. Farm visits are therefore considered an important part of benchmarking.

(ii)   Formal Benchmarking

Formal benchmarking codifies essential knowledge that takes farmers through the following minimum steps: (a) Examine their own farms and look for areas for improvement, (b) Identify a similar farm that is performing better, (c) Compare the performance of different farms and find reasons for differences, and (d) Plan and introduce changes to their farms based on what they have learned. Formal benchmarking provides a standard for comparison. It can be applied to: (a) Compare the performance of any farm with a more successful farm, (b) Compare current farm performance with the past performance of a farm, (c) Compare a farm plan with the actual outcome, (d) Compare production levels to check if the farm is technically efficient, (e) Compare production costs to check if the farm is economically efficient, (f) Examine the production and marketing processes to see if they are sound, and (g) Learn from the experience of other farmers and generate new ideas.

(iii)   Internal Benchmarking

Internal benchmarking takes place when the performance of the farm business is compared with itself. This is an internal health-check assessment of past results to determine ways to improve. Over time the farm business is analyzed, performance is measured, weaknesses and opportunities are identified, and on this basis improvements can be made. The challenge is to know what farmers can do to improve performance once lessons have been learned.

(iv)   External Benchmarking

External benchmarking involves comparing the performance of a farm business with the performance of other farms that have similar farm enterprises. The benchmark may be a

competing farmer or simply a successful one who is ready to share his or her good farm management practices with other farmers in the vicinity. Either way, the benchmark farm (whether real or hypothetical) serves as a demonstration of how things should be done.

The concept of Farming as a Business via Benchmarking (FAABB) is then referred to when benchmarking is applied to formally analyze farming business practices as a tool for decision making. In other words, it is difficulty to conduct FAAB without undertaking benchmarking. However, the current practice by EOs is dominated by informal benchmarking due to lack of tools. Furthermore, in rural areas, benchmarking for smallholder farmers is largely internal, which poses a big challenge because most of the decision-making cannot be undertaken without a comparative analysis with external data.

2.2.3 Knowledge Codification as a Formalization Tool for Farming as a Business via Benchmarking

Knowledge codification is the representation of knowledge so that it can be reused by either an individual or an organization. In other words, it involves converting tacit knowledge into explicit usable form. The transformation of tacit knowledge into codified knowledge extends beyond the contexts of knowledge application and increases the knowledge value due to high levels of exploitation. In other words, the main economic benefit of this process lies in the standardization and reuse of FAABB knowledge (Bettiol *et al*., 2012).

Although benchmarking and knowledge codification are useful tools by themselves, but together they greatly benefit from each other. On the one hand, benchmarking is extremely useful in developing FAABB knowledge to be codified. On the other hand, managing knowledge and effective knowledge codification is a very important tool for conducting benchmarking studies (Jetmarová, 2012).

Modern knowledge codification systems use mobile devices such as mobile phones and tablets for collection, analysis, and sharing of sensor data in order to form a body of knowledge, and actuation of people using this knowledge. Therefore, a knowledge codification framework generally consists of four successive phases: Collect, analyze, share and actuate (Saiz-Rubio & Rovira-Más, 2020).

(i) The Collect Phase

This phase includes collecting data from EO-carried sensors (such as mobile phones and wearable soil sensors), static sensors (such as sensors embedded to polls), and human input

(such as free-text input). The EOs participation is the fundamental element of FAAB knowledge codification systems but the main challenge of the knowledge systems is motivating them to participate in collecting data, since these systems consume resources of devices and EOs' times. The EOs do not want to be volunteers to submit their data for codification unless they benefit from the system. Moreover, participants would tend to be free riders and not contributors (Jetmarová, 2012).

(ii) The Analyze Phase

The analyze phase consists of analyzing the data collected in the collect phase. In this phase, simple statistical techniques and complex methods such as machine-learning techniques are used to analyze sensed data, and transform collected data into meaningful information. Detection of crop disease and insect pest using modeling and geographic information system are examples of data analysis in the knowledge codification systems.

(iii)   The Share Phase

The share phase is required to disseminate the analyzed information. In this phase, the analyzed information is visualized on the mobile phone, back-end servers, and monitors in the off-takers' offices. Web portals (Neilsen & Landauer, 1993), social networks (e.g., Facebook, Twitter, Skype), and virtual simulators (Tullis & Stetson, 2004) are some examples of the sharing platforms. Preserving privacy, authenticity, legality, accuracy and legibility of shared data are important issues of consideration in the share phase.

(iv)   The Actuate Phase

In this phase, an output of the knowledge codification system actuates a crop, a person, a group of people or another system (Saiz-Rubio & Rovira-Más, 2020). Automated methods may match analyzed data and predefined patterns, and triggers actuation if they detect matches. Ensuring the accuracy of actuation is the challenge for the actuate phase since inaccurate matches may mislead the EO and results into farming problems.

Technological developments increase the capabilities of mobile devices in terms of codification, storage, processing power and communication for FAABB. Consequently, knowledge codification is also referred to as mobile codification (Roberts, 2009).

2.3   Mobile Frameworks for Farming as a Business via Benchmarking

A mobile application development framework (or simply mobile framework) is a software development framework and its supporting infrastructure that is designed to support mobile app development. It also acts as a software library that provides fundamental services (libraries) to support the development of applications for a specific environment. It is also a software framework that allows developers to take an existing mobile web application or mobile app and transform it into a mobile app for another platform.

The main advantages of a mobile framework are: (a) It enables the design of apps through well-known concepts and facilities at the right level of abstraction, (b) It supports multi-site, real-time modelling across different stakeholders involved in a mobile project, (c) It abstracts from specific technologies so as to maximize reuse, while supporting the mobile application deployment into various platforms, and (d) It enables an early validation of design decisions through incremental prototypes and analysis techniques (Franzago *et al.*, 2014).

As a direct implication from the observations in Section 2.2, this research is concerned with enhancing the design and development activities of data-intensive mobile applications, i.e., those applications whose primary purpose is to present a large amount of content to a variety of possible users. A data-intensive mobile app framework differs from other mobile apps because of their: (a) Support for delivering content to multiple devices, (b) Focus on browsing collections of data and basic interactions with data items, with simpler functional requirements, (c) Focus on information organization and navigation design where users can directly understand the structure of the mobile app, (d) Support of one-to-one content delivery, where each user must have the impression of interacting with an interface specifically tailored to customized needs and preferences, and (e) Simpler transactional requirements, in most cases limited to high-performance read-only access and standard write operations of a well-delimited part of data.

Figure 2 depicts a typical framework for data intensive mobile apps (Xin *et al*., 2015). Explored in the Fig. 2 are the current state of support for mobile framework for FAABB across four dimensions namely: (a) The FAABB business process support, (b) The FAABB internal benchmarking support services, (c) The FAABB API support services, and (d) The FAABB Data storage support services.
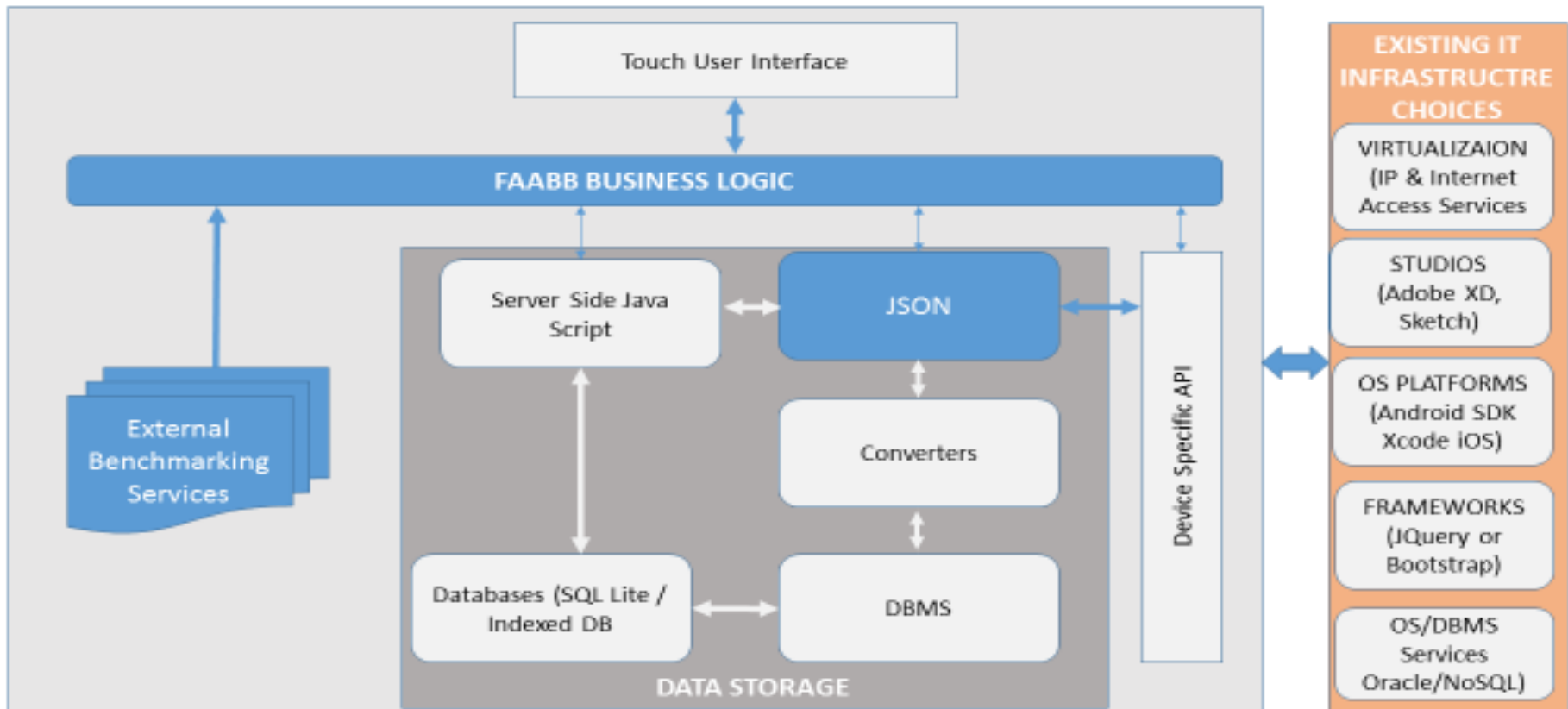
Figure 2: A Data-Intensive Mobile App Development Framework (Xin *et al.,* 2015)

2.3.1 Farming as a Business via Benchmarking Business Process Support Through Mobile Apps

Smartphones are now being used by producers for monitoring and evaluation in agriculture (World Bank, 2010), and managing operations, ranging in everything from robotic milkers, to wind machines that churn up the air in an attempt to thwart extreme weather in vineyards. A survey by Xin *et al*. (2015) shows that opportunities for mobile technology are ample, and below are only some example domains for mobile apps.

(i)   Market Information

Provides real-time agricultural market information. An example is Commodity Prices by Jaybus and Agriculture Price Alert by Ming (2011).

(ii)   Extension Services and Mobile Learning

Learning from mobile devices have been adopted from education institutions and similar approaches can be used to deliver Extension publications and learning modules, which can be downloaded on a mobile device, and read in a farm field. An example is Electronic Data Information Source (EDIS) developed by the University of Florida's Institute of Food and Agricultural Sciences (UF/IFAS) (https://ics.ifas.ufl.edu/).

(iii)   Weather

Specific tailored for agricultural weather information and management tools to assist farmers on decision making. Examples are Florida Automated Weather Network (FAWN) by UF/IFAS, and Weather Underground by Weather Underground (http://fawn.ifas.ufl.edu).

(iv)   Pests, Plant Disease Diagnosis and Plant Nutrition Management

The mystery of a pest or plant disease can now be solved in a matter of minutes by snapping a quick photo on a smartphone and consult with specialists and clinics in a plant diagnostic network. Examples of these apps are Distance Diagnostic and Identification System (DDIS), Southeast Landscape Pest (slPest) and National Plant Diagnostic Network (NPDN) Citrus Diseases developed by UF/IFAS.

(v)   Agricultural News

Provide subscription management and up-to-date, scientific based, unbiased, relevant news to users through mobile apps or social media. Examples are AgWeb News & Markets by Farm Journal, Inc. and Subscribe by UF/IFAS (https://www.agweb.com/).

(vi)   Geo-based Management and Information

Map related farm information and management tools, farm mapping and Best Management Practices (BMP). An example is SoilWeb developed by Dylan Beaudette (Beaudette & O'Geen, 2009).

Financial Calculation and Payment

Order products and payment through mobile environment. Examples are Mobile Pay by Bank of America Merchant Services and PayPal by PayPal Mobile (https://www.paypal.com/us/home).

Data Visibility and Product Tracking

 Collecting farm activity data and tracking agricultural products from farms to consumers for food safety. An example is HarvestMark Food Traceability by YottaMark, Inc.

Agricultural Emergence Management

Local and regional resources to cope any agricultural outbreaks and disasters. An example is Florida State Agricultural Response Team (FLSART) by UF/IFAS.

Management, Monitoring and Data Collection Tools

Tools that help farmers' daily management and monitoring needs. An example is SeedStar developed by Jon Deere.

2.3.2   Farming as a Business via Benchmarking Internal Benchmarking Support through Mobile Apps

Supporting FAABB entails codification (i.e. collection, processing, reporting and actuation) for the purpose of supporting EOs through their hand-held mobile phones. Doing benchmarking and transferring best practices for ARD is much more effective when it focuses not on just one or two measures, but require consideration of numerous key production and

financial benchmarks involving best practice comparisons with farms that do a good job with respect to personnel management, marketing their crops, transition planning, or purchasing assets, etc.

Qiang *et al.* (2011) summarize how the 15 case studies, considered to best represent m-apps in the three case study countries, are placed in the typology for agricultural and rural development. The study provided eight FAABB related critical application areas as: (a) Price information, (b) Market links, (c) Extension and support, (d) Distribution, logistics, and traceability (e) Resource management, (f) Labour migration and human development, (g) Governance issues, and (h) Rural finance infrastructure.

Observable from Table 3 none of the existing m-apps has more than three FAABB tools. This reveals that none of the existing applications has an embedded model to fully facilitate FAABB. Many articles discuss only one or two benchmark measures without considering other measures. This may provide a slanted view of how a farm is performing.

Table 2: Mobile-Apps Providing Benchmarking Support Services for Farming as a Business via Benchmarking

No.	Country – m-App Name	Critical Application Areas							
		A	B	C	D	E	F	G	H
1	Kenya - *KACE App	■	■						
2	Kenya - *DrumNet App	■	■						
3	Kenya - *Virtual City		■		■				
4	Kenya - *Kilimo Salama		■						
5	Kenya - KenCall Farmers' IS			■					
6	Kenya - Mkulima iCow			■					
7	Kenya - *Grundfos Lifelink					■			
8	Kenya - Kazi560 /Mobile4Good						■		
9	Kenya - Jana						■		
10	Kenya -*Ushahidi							■	
11	Philippines - b2bpricenow	■	■						
	Philippines: Project Mind						■		
12	Philippines-Farmers Texting Center		■	■					
13	Philippines - TXT CSC							■	
14	Philippines - text2teach						■		
15	Sri Lanka – Agri Extension			■					
16	Sri Lanka - Dialog Tradenet	■	■						
17	Sri Lanka - e-Dairy			■					
18	Sri Lanka - Gov't Center	■						■	

Qiang *et al*. (2011)

2.3.3 Farming as a Business via Benchmarking External Benchmarking Support Services through Application Programing Interface

The APIs are mobile technology enablers for achieving external benchmarking. At their simplest level, APIs enable communication between disparate software applications. Developers can connect APIs from different companies and services to achieve specific results (Xin *et al*., 2015). Popular API applications include enabling the implementation of libraries and frameworks across languages, specifying the interface between an application and an operating system, manipulating remote resources through protocols, and defining the interface through which interactions happen between a third-party and the applications that use its assets. From independent mobile developers and web developers to large enterprises and governmental agencies, APIs are increasingly leveraged across industries and use cases.

Although each application is unique and may need a specific solution, a common framework is necessary that allows developers to develop apps once and deploy them simultaneously on multiple platforms. It is important to select a framework that allows developers to concentrate on the business logic instead and not on the platform-specific technical implementation details (Xin *et al*., 2015).

Dospinescu and Perca (2013) present the two dimensions of creating the server and client connections (Fig. 3). One can either use service-oriented architecture (SOA) or web oriented architecture (WOA). These prescribe how to use web services to connect the client with the server so they could share data. The SOA uses SOAP as its protocol and uses Extensible Markup Language (XML) as its API data access language, while WOA uses Representational State Transfer (REST) protocol that uses JavaScript Object Notation (JSON) as its API data access language. Unfortunately, to date there is no single institution in Tanzania that provides support for FAABB external benchmarking services. Mobile apps developers are individually struggling to acquire external data but end up being frustrated because most of the data needs subscription and fees for their access.
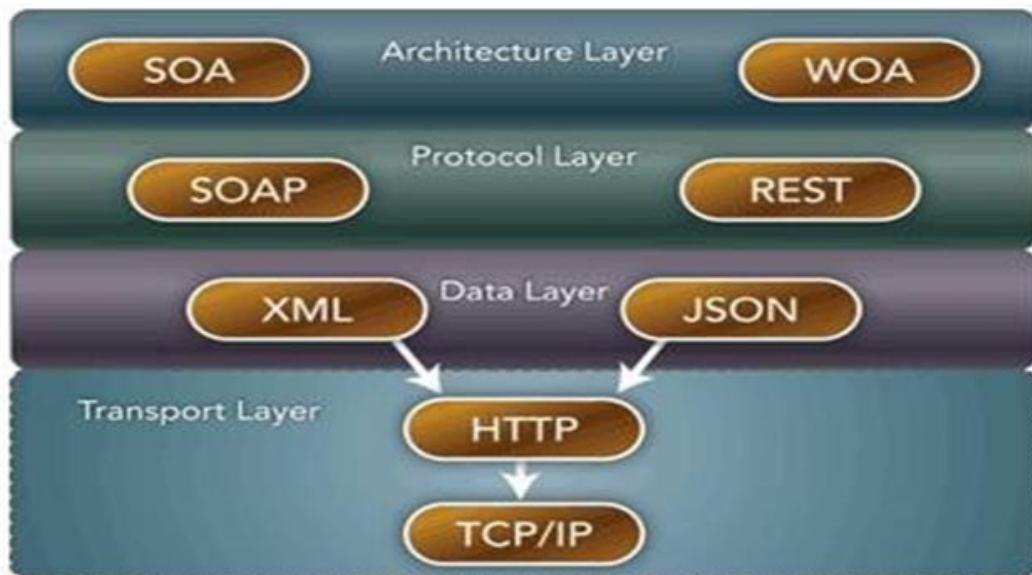
Figure 3: The Layers of Service-oriented Architecture and Representational State Transfer (Dospinescu & Perca, 2013)

Representational state transfer was considered and selected because it is being used with dominant mobile platforms that have a significant impact on the industry. For example, most of the new public web services from large vendors (Google, Yahoo, Amazon, Microsoft) rely on REST as the protocol for sharing and merging information from multiple sources. Some of its features include: (a) The ability to reduce the effect of network instability because REST is stateless, (b) Representational state transfer is easy to invoke because it is Uniform Resource Locator (URL) based, (c) Uses Hypertext Transfer Protocol (HTTP) methods, and (d) Returns data objects in XML and/or JSON. A custom Software Development Tool Kit (SDTK) can be used to convert a relational data into a JSON object in a typical development environment.

2.3.4 Farming as a Business Via Benchmarking Data Storage Support Services through Mobile Apps

Relational Database Management Systems (RDBMS) have been very successful at managing structured data with well-defined schemas. Despite this, relational systems are generally not the first choice for management of data where schemas are not pre-defined or must be flexible in the face of variations and changes. Instead, Not only Structured Query Language (No-SQL) database systems supporting JSON are often selected to provide persistence to such applications. The JSON is a light-weight and flexible semi-structured data format supporting constructs in most programming languages (Jowan *et al.,* 2016).

The recent explosion of compostable cloud services offers some compelling ways to resolve the NoSQL analytics challenge, for three key reasons (IBM, 2017):

(i)   Data generated by Internet of Things (IoT), web and mobile-based systems of engagement should be managed and maintained in its native environment (the cloud) rather than moved to on-premises systems for analytics.

(ii)   Data generated by systems of engagement lacks the sophisticated schema of traditional systems of record, which makes it difficult to store this data for analytics using a relational data warehouse. Retaining data in the cloud allows for on-demand analytics, leveraging a simple integration between a JSON database service and a relational cloud data warehouse, with minimal requirement for data movement or transformation. By leaving database management to expert service providers, you can focus your attention on activities that provide a competitive advantage in the marketplace.

(iii) With the right platform, the data of the future; the data created by new, disruptive technologies can be fully exploited in a cloud-based data warehouse.

The NoSQL databases are sometimes referred to as cloud databases, non-relational databases, distributed databases or Big Data databases (Jowan *et al*., 2016).

Recently, a new era of application development is emerging, which is based upon big data technology and the ease of access to computing resources, such as mobile devices. All these issues can be better supported using JSON (and JavaScript) technology. Almost all relational database systems have integrated JSON, partly according to the specification given in the American National Standards Institute Structured Query Language (ANSI SQL) standard and partly according to other specifications (Petković, 2017). For example, Oracle has implemented the most concepts specified in the ANSI SQL/JSON standard (Drew, 2019).

2.4   Related Work

In this section, the related work is classified into three groups. The first group consists of studies related to the FAAB decision process. The Benchmarking related studies are covered in the second group. The third group covers studies related to mobile frameworks.

2.4.1   Farming as a Business Decision Process Related Studies

(i)   Phase 1: Domain Recognition

Current FAAB systems are largely dominated by modelling defining factors for either crops or livestock systems. Cropping models have either been functional or mechanistic, depending on the modelling team's knowledge of the system, their purpose, the availability of data for cropping parameterization, and their experience in developing and evaluating models. These differences lead to different models producing different responses when used to simulate the same experiment (Jones *et al*., 2017b).

The factors to which models respond vary and evolve as modelers attempt to make them more comprehensive and universally applicable. In contrast, some researchers who want to apply them do not have all needed inputs, or they may want to embed a crop model into economic or other models for analyzing responses across scales (Dias *et al*., 2016).

Livestock systems are complex and require modelling at several levels: The animal, the herd, and its interactions of the herd with its environment through consumption of feed, use of land and water, and other resources. Several types of models have been used in the past to describe different components of livestock systems (Tedeschi *et al*., 2014).

A critical observation is that, the current modelling practices in defining factors for FAABB systems are dominated by individual line subsectors operated largely independently, with very little complementarity between them and their agronomists. The defining factors for FAAB should take into account the components of soil, water, crops, livestock, labor, capital, water and other resources, with the farm family at the center managing agriculture and related activities.

(ii)   Phase 2: Product Characterization

The FAAB system design and development are influenced by the understanding of crop and farm characterization and management practices (Africa & Adesina, 1995). Specific models and IT systems are developed to: (a) Identify factors influencing crop choice and rotations on farms (Dury *et al.*, 2012), (b) Evaluate effects of management practices on crop performance indicators (Schönhart *et al*., 2009), (c) Investigate farmers' perceptions and adaptation strategies to climate change (Elizabeth & Medina, 2016), and (d) Explore linkages between marketing channels, farm characteristics and biodiversity (Mirschel & Wenkel, 2017). At present, existing models are parameterized for different crops but rarely for different crop

varieties (Jones *et al*., 2017b) and farmers need to develop their adaptive capacity. To support this process, agricultural research has developed two main approaches: (a) Hard approaches that are mainly science-driven and rely on simulation models, and (b) Soft approaches that rely fully on stakeholders' knowledge. Both approaches present several drawbacks to achieve relevance to real-world decision-making and management.

A conceptual framework hybridizing hard and soft approaches to develop farmers' adaptive capacity is being advocated but no system exists that can facilitate the hybridization modelling (Martin & Martin, 2017). Furthermore, the types of land management practices farmers use differ across different ecological zones, which further justifies modelling of farm characterization and management practices (Economists & Africa, 2010).

(iii)   Phase 3: Simulation Systems for Optimal Farm Production

Various researchers have developed a reduced-form of crop models that can be interpreted as the "production function" that is the foundation of economic production models (Jones *et al*., 2017b). Production function can be linked to economic models to create "hybrid" models for policy analysis and impact assessment. Similar processes of model development are evaluated in Gaydon *et al*. (2017), building from the foundation of a comprehensive set of crops, soil, and water management system simulations in Asia.

Tedeschi *et al*. (2014) confirms that several types of models have been used to describe different components of livestock systems. They concluded that livestock systems are complex and require modelling at several levels: The animal, the herd, and its interactions of the herd with its environment via consumption of feed, use of land and water, and other resources. Examples of these are Decision Support System for Agro technology Transfer (DSSAT) (Dias *et al*., 2016) and Agricultural Production Systems Simulator (APSIM) (Gaydon *et al.,* 2017).

Sood and Rana (2015) testifies the application of Geographic Information System (GIS) to precision farming, satellites, drones, web maps and sophisticated models. The modern-day farmer needs to understand a lot more than just what to seed are soils, weeds, nutrients, weather, insects, disease, machinery and climate. Stone and Meinke (2006) addresses the challenges of weather and climatic patterns simulations in linking climatological information with a wide range of farming decisions.

Farm management practices are also affected by Calendar (Date and Time). Event triggers are required as functions of calendar not only for the reasons of alerting farmers of the upcoming events during the production life cycle but also to interact with other modules to simulate the input values in the context of the environment (Kyaruzi *et al.*, 2019b). In particular, while a considerable amount of climate information is now available to farmers, most of the information are focusing on isolated factors, which are ill-suited for use by rural farmers for some of their decision-making.

(iv)   Phase 4: Limiting Factors for Agricultural Optimization

Donatelli *et al.* (2017) discusses the coupling of pest and disease models (as limiting factors) with crop models (as defining factors). The study proposes a roadmap to improve pest and disease modelling focusing on improving the data resources available for parameterization and validation, bettering the coupling of crop to antagonist models, and creating a community of researchers that can collaborate to share expertise and produce community tools.

Modelling has also proved valuable in assessing possible pest risks and in guiding general policy development (Diekman *et al.*, 2012). One of the applications of population genetics to weed, pest and disease issues in agriculture are models of the evolution of resistance to pesticides, and of the dynamics of plant diseases (Denison, 2012). The major weakness of these models is their inability to predict their negative or positive influence on the expected yields (that are predicted in Phase 3).

(v)   Phase 5: Data Analytics for Post Farming Evaluation

A number of approaches have been developed to model the economic implications of decisions and policies for a range of scales and purposes. In National Research Council (NRC, 2001), authors developed animal performance models that use animal performance as a central element driving production, profitability, and efficiency in livestock systems. Since then, the most commonly used livestock models are those that predict animal meat and milk productivity. Nutrient requirements models are the workhorse of the feed industry for ration formulation and for recommending changes in feed management to farm advisors. Although these models are good for calculating feed requirements, they are less accurate in predicting the nutrient supply to animals under a wide range of conditions (Tedeschi *et al.,* 2014; Stone & Meinke, 2006).

Linear economic optimization models of farm systems that were developed in the 1950–60s provide a basis for prescriptive farm management advice (Mirschel & Wenkel, 2017). These models are characterized by a complex set of linear inequality constraints that represent the production possibilities available to a farmer. Just *et al.* (1983) reports on econometric methods developed and used for single function models, single-equation models, and simultaneous system models that represent input demand and output supply behavior for crop production. However, the econometric approach has limitations in its ability to extrapolate responses that are outside the estimation sample, or those that employ systems that are not present in the data sample (Antle & Capalbo, 2000).

As briefly mentioned in this section, most of the studies support individual stages of the FAABB decision process, by modeling specific activities for serving specific purpose. No single FAABB process model offers a holistic and integrated approach to address the challenges of EOs in their activities by using the holistic farming decision framework at its foundation.

2.4.2   Benchmarking Models and Related Studies

Benchmarking modelling from a widely-used econometric risk behavioral model has also been analyzed (Hazell, 2015). Flichman (2012) describes recent studies on application of models that combine bio-physical and economic models to influence benchmarking mechanisms in agricultural systems. The studies characterize bio-economic models into farm, landscape, regional, and national models. Systems in each of these scales include crops, livestock, and socioeconomics components that interact in complex ways.

Majewski (2013) devised a "*Farm Sustainability Index*" (FSI) model for measuring farm level sustainability using "Multiple Weight Method"**.** The model covered measures that assist in providing benchmarking systems for farmers along five variables: (a) economic sustainability, (b) environmental sustainability (e.g. fertilizer application, use of pesticide, sewage management, etc.) (c) social sustainability (e.g. training courses, household facilities, etc.), (d) Production and farm management practices (e.g. crop rotation, soil testing, calcium fertilization, animal welfare, etc.) and, (e) Production space (e.g. soil quality index, soil acidity, etc.). While producing a comprehensive list of benchmarking measures, the FSI model is criticized by ignoring the defining factors in the modelling; consequently, relying on the farmers' interviews as opposed to capturing live data from the fields.

Studies have argued the complementarity of the concepts of benchmarking and knowledge management. On the one hand knowledge management is achieved through benchmarking. On the other hand, benchmarking is better achieved through knowledge codification and management (Jetmarová, 2012). It is the later one that adds value to this work.

First, knowledge management can facilitate collaboration with other enterprises and knowledge transfer across boundaries through ensuring that experts with relevant expert knowledge have opportunity to share their tacit knowledge through collaboration, which is needed for external benchmarking. While doing external benchmarking, EOs have to work collaboratively across organizational boundaries to ensure sustained innovations and competitive advantage. Second, knowledge codification assists in converting EOs' tacit knowledge to explicit knowledge. This adds a lot of value to the community as it is known that knowledge is available, and it is retrievable for future re-use.

As a data intensive activity, FAABB requires benchmarking modeling that is enabled by the knowledge codification tools, platforms and processes for tacit knowledge creation and sharing, which play an important role in external benchmarking.

2.4.3   Mobile Frameworks Related Studies

Greenberg (1997) testifies that mobile handsets are currently being used in nearly every country and community. The development of applications for them offers uses that extend well beyond voice and text communications. Consequently, mobile applications for ARD could provide the most economic, practical, and accessible routes to information, markets, governance, and finance for millions of people who have been excluded from their use. However, the published literature on mobile application development frameworks to support FAABB is rather limited.

Qiang *et al*. (2011) summarize 15 case studies that are considered to have m-apps functionality in the typology for FAABB in the three case study countries. The study provided eight critical application areas necessary for realizing FAABB: (a) price information, (b) market links, (c) extension and support, (d) distribution, logistics, and traceability, (e) resource management, (f) labor migration, (g) Governance/political issues, and (h) Rural finance infrastructure. These case studies and others that are emerging provide a need for a unified framework to deal with the complexity and diversity of FAABB applications.

As mobile technology moves forward, more options and better development tools will become available for mobile application development. Furthermore, applications today are increasingly developed using a three-tier internet architecture, are cloud-based, and use a Software-as-a-Service (SaaS) business model that needs to support the collective needs of thousands of customers (Jetmarová, 2012).

2.5   Summary

This chapter reviewed key literature in the fields of the FAABB decision process, as well as knowledge management/codification as its main tool, and presents the relevant studies from these fields of research. It also reviewed the existing mobile frameworks for assisting in achieving FAABB.

The FAABB decision process is an important area in achieving ARD. It includes decision making at individual stages of business process (i.e. domain knowledge recognition, farm characterization and management, simulation of predictable farm data, identification of limiting factors, and data analytics for post-farming evaluation) as well as making decisions for crosscutting issues (World Bank, 2010).

Understandably, FAABB in a particular farm is primarily facilitated by an EO, as a farm manager (supporting groups of smallholder farmers to achieve FAABB) (Kahan, 2010). These EOs have been suffering mainly from information deficit and knowledge gaps in processing the vast amount of data required at each stage of FAABB (Rwebangira, 2017). Collection and codification of information and knowledge for FAABB would greatly assists EOs in enhancing their experiences and use them for decision making throughout the FAABB lifecycle including: Selection of good markets; provision of cost effective extension and support services; managing logistics for input distribution and traceability; human resource management; contract negotiations; production management for profitability and efficiency; rural finance; etc. (Kyaruzi *et al.*, 2019b).

Although Information and Communication Technology (ICT) in general (Simba & Yonah, 2014) and mobile apps in particular (Mcnamara, 2009; Sanga *et al.,* 2016) provide promising results in assisting ARD, most of existing ICT solutions lack a unified framework for data capture and codification for undertaking FAABB. Though, some of these solutions also support benchmarking and knowledge codification functionality, but they provide limited support to address challenges of EOs in undertaking crosscutting activities across FAABB

stages. However, existing m-apps and ARD models assist decision making in the individual stages of the FAABB decision process (Kyaruzi *et al*., 2019a).

Furthermore, existing systems have largely been useful for conducting internal benchmarking due to lack of tools that would enable coordinated and standardized data exchanges across various actors involved in FAABB but located at different locations globally. This confirms a clear need for a framework that supports the provision of central repository for FAABB to facilitate external benchmarking. Such a repository would become a "clearing house" for FAABB data exchange services as well as a warehouse of FAABB data collected by participants as they engage in FAABB.

This research addresses this gap by providing a holistic framework for inducing FAABB to smallholder farmers by supporting EOs to generate information and codify knowledge necessary for them to participate in all stages of the FAABB decision process through their mobile phones. The specific research interest was, therefore, to design a mobile application development framework that facilitates data capture and codification to support EOs in conducting FAABB activities. The proposed framework has been nick-named as a **m**obile **F**ramework for **F**arming-**A**s-**A**-**B**usiness via **B**enchmarking (**m-FFAABB**).

MATERIALS AND METHODS

3.1 Design Science Research

Developing a mobile framework for FAABB (m-FFAABB) is a Design Science Research (DSR) undertaking. As an applied research discipline, Information Systems (IS) apply theory from other disciplines, such as computer science and social sciences, to solve problems at the intersection of information technology (IT) (Peffers *et al.*, 2006). Similarly, this research applies theory from a social science domain (i.e. ARD) to solve problems of farmers using mobile technologies as the intersection of IT. Applying an appropriate research methodology empowers the research for contributing to the body of knowledge in a given discipline (Peffers *et al*., 2006).

This chapter presents, advocates, and evaluates a soft system methodology (SSM) applied to DSR. The DSR, through SSM, provides an approach to the development of new ways to improve ARD, particularly with respect to social aspects, through the activities of design, development, instantiation, evaluation and evolution of a technological artifact. The considered research approach merges the common DSR process (design, build, evaluate) together with the iterative SSM. In practice, the design-build-evaluate process is usually iterated until the specific requirements are met. Then, the generalized requirements are adjusted as the process continues to keep alignment with the specific requirements. At the end, the artifact exemplifies a general solution to a class of problems shown to operate in one instance of that class of problems.

In recent years, several researchers have shown the validity and value of DSR as a research paradigm that specialized for IS discipline (Hevner *et al.,* 2004; Peffers *et al.,* 2006; Gregor & Hevner, 2013). Therefore, the DSR paradigm was adopted to drive the research methodology of this study.

3.1.1 Methodologies in Design Science Research

The DSR has been cast as a paradigm rather than a discrete research methodology. Its basic approach approximates the common view of the "scientific method" so closely that it seems acceptable as an assumption. The researcher learns about artifacts and natural settings by formulating hypotheses (a design), conducting an experiment (instantiating an artifact), and matching the results to the expectations (evaluating). Consequently, the major seminal works

in information systems DSR have been concerned with its relevance in the philosophy of science, the type of theory in DSR, and criteria for evaluating DSR (Baskerville *et al*., 2009).

3.1.2 Iterations in Design Science Research

The DSR has not usually been regarded as an iterative process (Baskerville *et al.*, 2009). It is, instead, mostly regarded as episodic consisting of four activities: (a) Search, (b) Ex Ante Evaluation, (c) Construction, and (d) Ex Post Evaluation. This approach assumes that problem identification and specification is part of the search process that develops the framework. The two major products in the method are the framework and the artifact. The "scientific" learning arises from the search process, the construction, and the two evaluations. An episodic approach is appropriate where the design can be relatively complete and final in its specification and the evaluation of the artifact will complete the research project (or episode).

It certainly seems likely that this method can be episodic. Operating this method iteratively means that the framework and the artifact must be regarded as tentative, and it suggests that these must necessarily be simpler and cheaper if the process is to be repeated multiple times. Such an approach can be represented as shown in Fig. 4 (Baskerville *et al.,* 2009).

Existing iterative methodologies applied to DSR include prototyping methodology (PTM), action research methodology (ARM) and SSM. After considering all these possible methodologies, the SSM was found suitable and therefore chosen for managing iterations for DSR framework development. The reasons for choosing SSM are further expanded in Section 3.2.
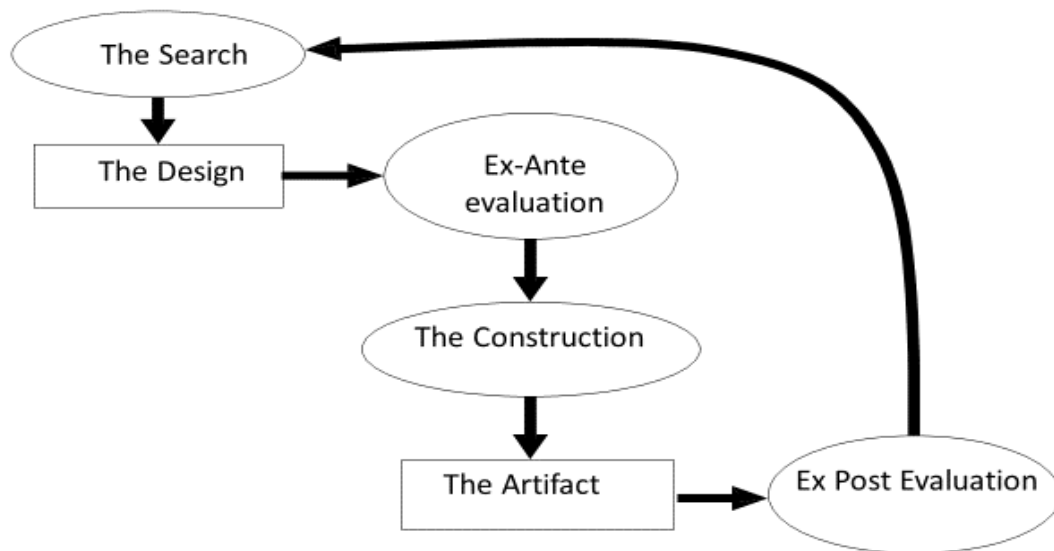
Figure 4: Iterative Design Science Research Method

3.2 The Soft System Methodology

The Soft Systems Methodology (SSM) is suited for dealing with ill structured complex problem situations that have human activity component (Baskerville *et al*., 2009). The SSM is a prominent systems science approach to social-technical problems. Since it emerged from the juncture of action research and systems science, it is regarded as a form of action research. The SSM differs from other methodologies that try to solve hard problems that are technologically oriented. Soft problems are complex while hard problems are easy to define in such a way that the HOW and WHAT can be defined before obtaining a solution (Sanga *et al*., 2016).

3.2.1 The Soft Systems Methodology in the Design Science Research

There are different published versions of SSM as it has developed over the years. Figure 5 depicts the basic stages of SSM.
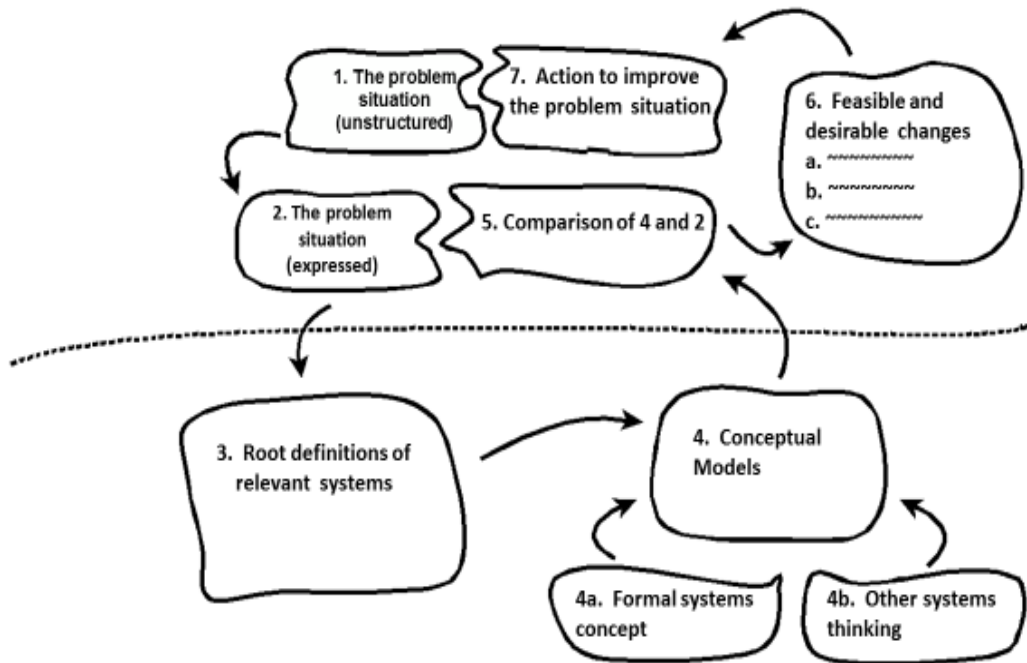
Figure 5: Soft Systems Methodology Research Methodology

In a real world problem, a number of relevant systems can be identified depending on the researchers' understanding of the problem situation. Each relevant system needs a purposeful action that can rectify the problem situation, which also depends on the world view of the researchers' and participants. These identified participants act as stakeholders who initialize the debate about the actions for changes of a real world problem according to their interests. In order to have a clear purposeful action of a relevant system a root definition must be formulated (Zarei *et al.,* 2014). The adoption of SSM in the DSR is based on the following axioms: (a) Design science problems do not exist independent of human related situations, they are constructs of the concerned mind, defined by individual world view; therefore, look not at the problem but at the situation, (b) Interrelationship of design science problems creates a 'mess' (multiple problem situation) that requires consensus of involved parties as part of the solution, (c) Worldview - different (and equally valid) interpretations of the design science world by each individual, (d) Corollary of 1, design science solutions are also intellectual constructs and no 'problem' exists in isolation, (e) Improvements in design science situations are most likely through sharing of perceptions, persuasion and debate. Analysts should be interactive/therapeutic rather than expert, and (d) Designers and analysts cannot be divorced from the problem.

3.2.2   Iterations in Soft Systems Methodology

In SSM, iterations are organized as switches between the real world and the systems thinking world, and iterates where appropriate as shown in Fig. 5. Stage one is the first of two stages that explore a problematic situation within the real-world frame of thinking. In stage two, the unstructured views of the problematic situation are given more structure and expression, in ways that stakeholders can understand them, that focus on the essence of the situation, and that identify relevant themes. Key aims are to develop a shared understanding of different perspectives and to create a basis for further discussion in later stages. Stage three represents a shift from real world thinking (about perspectives on what is, what is undesirable or desirable, and why) to system thinking (using systems concepts and system-thinking-inspired techniques). Stage three is about debating various viewpoints, defining what stakeholders want in a relevant system (as a solution to the problematic situation), and selecting one (or more) definition(s) for further consideration in stage four.

In stage four, conceptual models are constructed, based on agreed root definitions of the desired system. A conceptual model represents desired human activities. Stage five represents a shift back from system thinking to reconsider how the conceptual models developed in the system thinking world can fit into the real world. Comparisons are made between conceptual models and the problem situation expressed. Stage six considers whether the identified areas for improvement and change determined in Stage five can be accepted and integrated into the culture. Finally, Stage seven should determine the scope of the action, who is to take action, what kinds of action should be taken, in which areas and when. Following action taking, further iteration may be taken to assess the problematic situation and determine whether sufficient improvement has been made and why or why not. Continuing problems may be the motivation for another cycle (or episode) through the SSM process.

Figure 6 provides a shorter version of SSM model as advocated in Sanga *et al.* (2016). First the problem situation which exists in a real world must be identified by the researcher. Then relevant systems of purposeful activities are selected with the purpose of improving the situation of concern. The purposeful activities involve any system/action which is implemented to improve the problem situation. The models from the relevant systems are then compared with the perceived real world and again purposeful action is taken to improve the problem situation. This mostly initializes another cycle of problem solving; thus the process is a cyclical process.
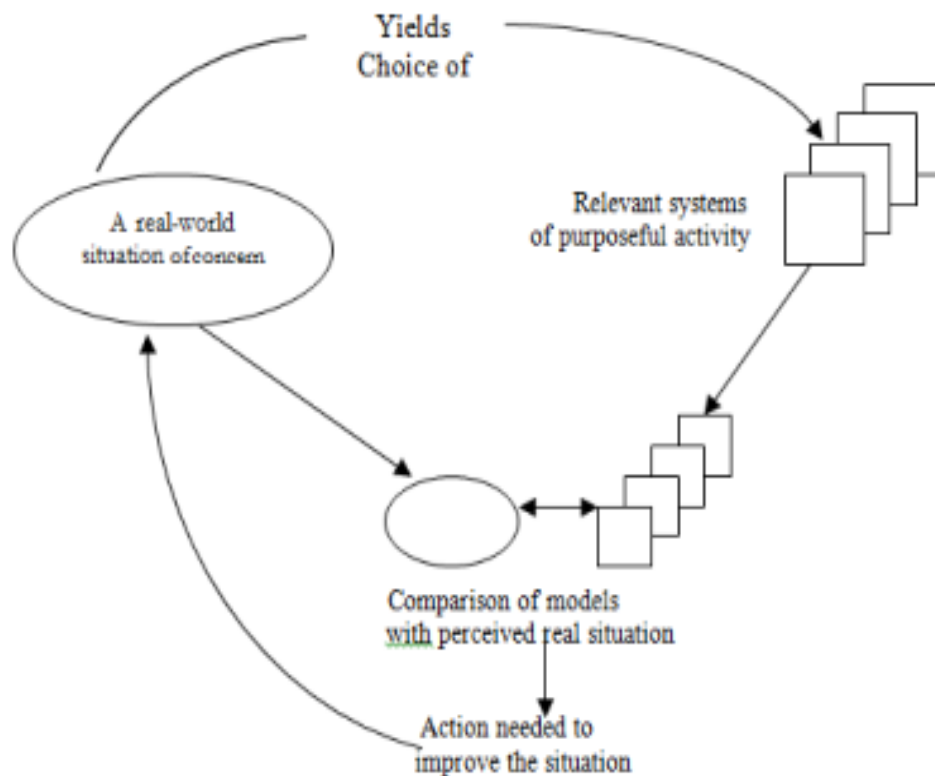
Figure 6: A shorter Version of Soft Systems Methodology Model

3.3   Building a Four Stage Framework through Soft Systems Methodology

In this research, a shorter four stage SSM model (Sanga *et al*., 2016) has been adopted for simplicity, with generalized activities in the stages and less complex iteration than the older seven stage model (Baskerville *et al.*, 2009). Figure 7 provides a sketch of the necessary iterations.

In Fig. 7, "A" represents a real world of concern which is "FFAABB", "E1 and E2" represent chosen systems for Crop Subsector (case study I) and Dairy Subsector (case study II) respectively. Similarly, "F1" (Kilimo Maendeleo) and "F2" (Farm Builder) represent respective relevant systems for purposeful activity and, "C1" (Mbeya) and "C2" (Njombe) represent perceived SAGCOT case study areas that are used for comparison of the models with real life situations as case studies, "D1 and D2" represent actions needed to improve the situation and "W" represent monitoring and taking controlled action as per established performance measurement.

3.3.1   Soft Systems Methodology Activity 1: Developing Problem Situation

The following description identifies some of the issues "in the real-world" (see "red items" in Fig. 8) which were considered to be problematic in this research work. Agriculture is the backbone of most African countries. In Tanzania, the sector is known for employing more than 70% of the total population. However, the sector is characterized by lack of information for undertaking benchmarking activities to facilitate FAAB including optimal utilization of the available land, managing water and human resources, provision of agricultural support services, and market-farmer linkages, etc.

In this study an attempt was made to design a framework that will facilitate the *data capture and knowledge codification* to support EOs in managing FAABB through mobile technologies for the two selected sub-sectors of agriculture (i.e. crop and dairy) within SAGCOT as a case study area. The real word of concern was therefore designing a ***mobile Framework for Farming as a Business via Benchmarking (m-FFAABB)***.
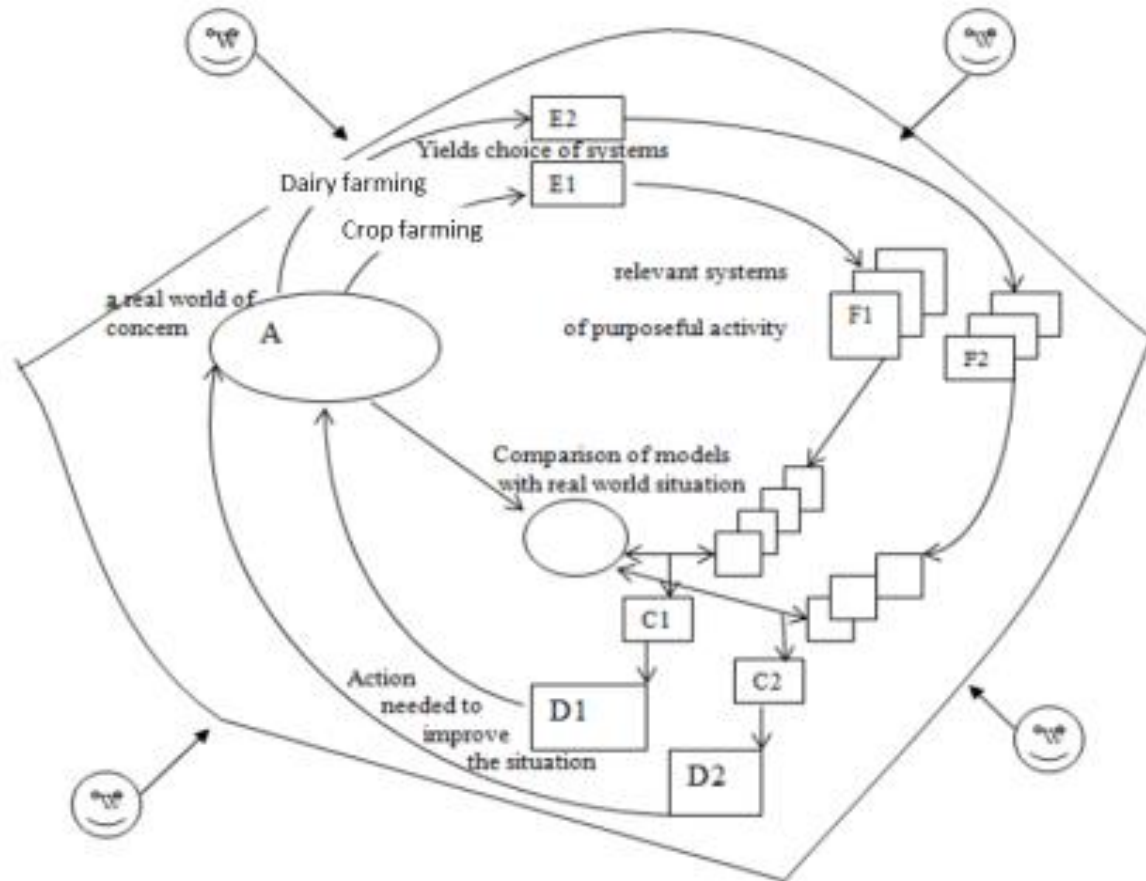
Figure 7: Case Study Setup for Mobile Framework for Farming as a Business via Benchmarking
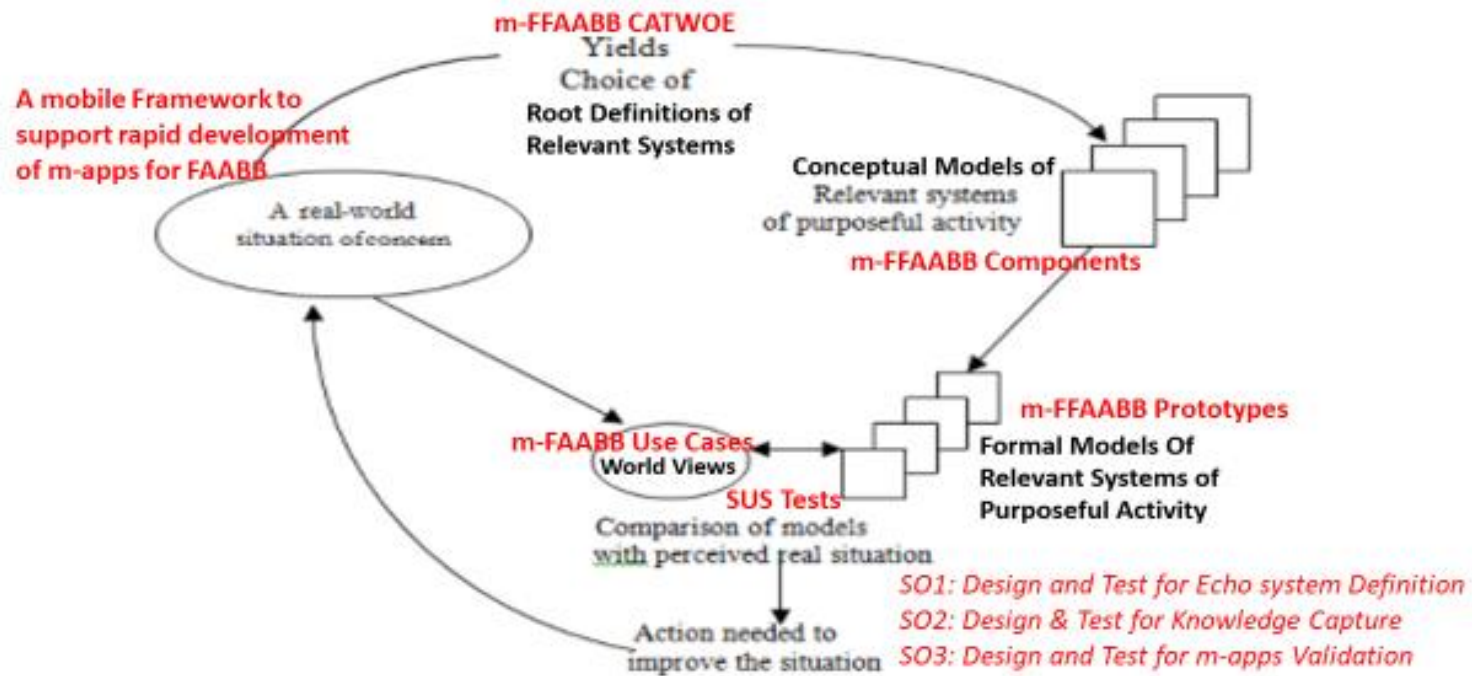
Figure 8: Applying Soft Systems Methodology Model to mobile Framework for Farming as a Business via Benchmarking

3.3.2 Soft Systems Methodology Activity 2: Development of Root Definition for Mobile Framework for Farming as a Business via Benchmarking

Organizations considering the development of mobile apps need to decide how mobile technology can support their mission, and choose scalable, quick to implement and affordable mobile solutions for their team and their projects. Although each app is unique and may need a specific solution, a common framework is necessary that allows developers to develop apps once and deploy them simultaneously on multiple platforms. It is important to select a framework that allows developers to concentrate on the business logic instead and not on the implementation details. Xin *et al.* (2015) provides a good guidance framework for developing a mobile app strategy.

First, it was considered and decided to leverage on existing/local web development skills and choose a set of technologies to deploy apps everywhere (mobile web and hybrid) using a single source codebase. After a review of available mobile development frameworks, a set of technologies for development was selected considering: a) leveraging existing development skills, b) covering multiple platforms for web, native and hybrid, c) local storage support, and d) past successful examples and long-term sustainability of vendors.

Second, a decision was made to focus on who was playing which roles in the diffusion and adoption of project results. Here a role model inspired by CATWOE (Customers, Actors, Transformation Process, Worldview, Owners and Environmental constraints) (Bergvall-Kåreborn *et al.*, 2004) was designed. The main idea behind this role model is that five roles must be filled if implementation is going to succeed. If one of the roles has not been filled, implementation will fail. The five roles were:

(i) The EOs (and/or farm managers) is a target group of those who are going to use the product.

(ii) The Southern Agricultural Growth Corridor of Tanzania Catalytic Trust Fund (SAGCOT CTF) is owner/sponsor of the framework responsible for initiating the implementation and scoping the direction. Towards the end of the implementation the owner /sponsor is also responsible for demanding the results coming out of the implementation of the framework/designs.

(iii)   Mtenda Kyera Rice Co Ltd for Crop and ASSAS Ltd, and Njombe Milk Factory for dairy were identified and selected as the actual implementers of the project. Often this role is named the project manager.

(iv)   Litenga Holding Co Ltd (on Crop) and Animal Breading East Africa (ABEA Ltd on Dairy) all being supervised and guided by the proposed framework were identified and selected as champions/ambassadors. These are the persons who actually make the people from the target group take the innovation into use.

(v)   Other secondary stakeholders considered consists of all other interested parties not taking any of the four primary roles. These include the Nelson Mandela African Institution of Science and Technology (NM-AIST) as technology infrastructure provider as well as research and innovation pioneers; then others included financial institutions, farmers, policy makers, etc.

3.3.3   Activity 3: Generating Conceptual Models of Mobile Framework for Farming as a Business via Benchmarking

Conceptual models of the proposed framework were designed across two basic views: (a) The m-FAABB driven by Internal benchmarking, imitates the data capture and analysis and codification components of FAABB as independent self-contained system, and (b) The m-FAABB driven by external benchmarking, imitates the data capture and analysis and codification components of FAABB as services imported from a central server dedicated to act as a clearing system for all desperate systems that are designed for specific domains and products.

The choice of "relevant systems" for the core components of m-FFAABB was done in two inception workshops with 20 key stakeholders each (i.e. EOs, processors, traders, researchers from NM-AIST, Sokoine University of Agriculture (SUA) and University of Dar es Salaam (UDSM), policy makers, transporters, IT solution providers). These stakeholders formed an innovation platform. It was formed in 2018 in Njombe for dairy case study and in Mbeya for rice case study. The results of the inception workshops helped to obtain user and system requirements, which later facilitated the development of the m-FFAABB.

3.3.4 Activity 4: Testing and Review of Mobile Framework for Farming as a Business via Benchmarking

In most forms of action research, this comparison is left as an implication of action planning. As the action plan is constructed, gaps or mismatches will grow more obvious. The main comparison stage is made in evaluating the outcome of the implementation of the planned action (i.e. post hoc). The research study at hand is not particularly different. Although it may not have been explicit, through workshops to selected EOs and off takers, reviews were made to improve the functionality of the framework components to accommodate variabilities of the domains and products specific implementations.

3.3.5 Activity 5: Testing and Review of Mobile Framework for Farming as a Business via Benchmarking Application Programing Interface

Since m-FFAABB is a data intensive framework, its realization requires external benchmarking services. This is justified by the fact that the framework should provide an API to not only "big-data" services for codification, but also an API that allows individual mobile apps developers to import/export data from/to the central server so that they could constantly be evaluated by back-office experts, who in turn provide additional advisory services to EOs. The agricultural external benchmarking services, therefore, reinforces the need for placement of "big-data" servers alongside a pool of experts with agricultural domain knowledge for conducting expert analysis and providing advisory services and training to EOs.

With the availability of "cloud computing, individual mobile apps developers for ARD will benefit from external benchmarking from a typical **"shared resource hub"** through APIs that support m-FFAABB, and develop multiple mobile apps tailored to different FAABB setup in rural areas. In this study, NM-AIST through the African Centre for Research, Agricultural advancement, Teaching Excellence and Sustainability (CREATES) was evaluated and found suitable as a **"shared resource hub"** for m-FFAABB.

The CREATES is a regional hub for innovative solutions to foster agriculture, food and nutrition security in the region, through research done by a critical mass of Master students, PhD scholars and Post doctorial fellows as well as running demand driven short courses, and seminars. The CREATES operates under the school of Life Science and Bio-Engineering (LiSBE) at the NM-AIST. Through NM-AIST, CREATES also enjoys the availability of supercomputers as well as ICT and modeling experts from the School of Computational and Communication Sciences and Engineering (CoCSE). Realization of m-FFAABB, therefore,

relies on NM-AIST as an external entity investing in both infrastructure and human resource for provision of "external benchmarking services".

For example, it is difficult for a mobile app developer to write an API to predict the suitability of a typical plant breed based on their soil structure and acidic levels because their apps do not have appropriate analytical tools at their fingertips. Once captured from the field by EOs, these apps will typically send sample soil measures to m-FFAABB servers at NM-AIST and notify designated expert at CREATES. The CREATES expert will test the soil and use m-FFAABB services to conduct comparative analysis of the sample against typical soil measures from benchmark farm. The m-FFAABB server will then reply to the client mobile app through an API. The client API will in turn configure the report and display it to the EO mobile phone.

Therefore, API testing uses a software that performs verification directly at the API level. It is part of integration testing that determines whether the APIs meet the testers' expectations of functionality, reliability, performance, and security. Unlike User Interface (UI) testing, API testing is performed at the message layer without GUI.

Since the experiments involved two different companies whose prototypes were developed using different tools. It was agreed and considered appropriate to let this type of testing be undertaken by the developers themselves by connecting to NM-AIST servers directly or through "cloud services". As a typical example of the envisaged differences: there are two broad classes of web service for Web API: SOAP and REST (see also Section 2.3.3). The SOAP (**S**imple **O**bject **A**ccess **P**rotocol) is a standard protocol defined by the W3C standards for sending and receiving web service requests and responses. The REST (Representational State Transfer) is the web standards-based architecture that uses HTTP. Although both embraces the JSON format, the choice of either of these web services affects the way specific API will be developed and tested. Therefore, testing for functionality was used to provide feedback to the developers of respective prototypes on potential areas for API improvements.

3.3.6 Activity 6: Testing and Review of Mobile Framework for Farming as a Business via Benchmarking Usability

The usability of m-FFAABB was tested through System Usability Scale (SUS) that was developed by John Brooke in 1986 (Tullis & Stetson, 2004). It allows evaluation of a wide variety of products and services, including hardware, software, mobile devices and websites. It is a simple, ten-item Likert scale with five response options for respondents; from "Strongly

agree" to "Strongly disagree". It provides a "quick and dirty", reliable tool for measuring the usability. The followings are the ten standard items of the SUS: (a) I think that I would like to use this system frequently, (b) I found the system unnecessarily complex, (c) I thought the system was easy to use, (d) I think I would need the support of a technical person to be able to use this system, (e) I found that the various functions in this system were well integrated, (f) I thought there was too much inconsistency in this system, (g) I would imagine that most people would learn to use this system very quickly, (h) I found the system very cumbersome to use, (i) I felt very confident using the system, and (j) I needed to learn a lot of things before I could get going with this system.

The SUS is widely used and has more advantages and less disadvantages (Martins *et al.,* 2015).

(i)   Uses of System Usability Scale

After Completing a Usability Test

 After participants have completed a task in an interface (a device or a program that is used to communicate with a computer), they have to answer the 10 questions based on the SUS questionnaire. For example, to understand a rough usability of software, hardware or a website. Although SUS cannot be diagnostic, (so survey responses are unlikely to tell what needs to be fixed in a product or service), however, it can help report the topmost issues in a product or service.

On Mobile Apps

 One of the best attributes of SUS is its adaptability. It can even be used in a mobile interface. Although mobile apps did not even exist when SUS was developed, yet it finds its usability in the same. One can collect response data on mobile apps like Facebook and Twitter using SUS questionnaire.

With Prototypes

 An interface doesn't have to be fully functional before deploying SUS survey. The best part is, one can still administer it even if a prototype is partially functioning. One can use SUS score as an early indicator of usability. Compare changes in the SUS score as they make changes to the prototype and finally the working interface.

To Test Partial Functionality

Some products, especially those in business to business enterprise, are quite complex. There are accounting software, HR software etc. that fall under this category. The software is complex, as they have various functions with different users. One can use SUS survey to analyze just one portion of functionality and not the complete product.

(ii)   Advantages of System Usability Scale

The SUS has a quick processing time. Since there are definitive 10 questions asked, respondents can quickly respond to the questionnaire. This results in quick processing of the information thus obtained. The SUS is desirable due to its versatility and applicability for various software, hardware or websites. Since the SUS score is simple to calculate, the results are easily obtained and can be worked upon for making a system perform better. Although System Usability Scale is not diagnostic, SUS is used to evaluate and pinpoint issues, thereby it helps in understanding where the problem lies. SUS has the ability to evaluate user satisfaction and is considerably inexpensive as compared to other similar methods.

(iii)   Disadvantages of System Usability Scale

The SUS is unable to provide accurate information on a product's weaknesses. It is not possible to make systematic comparisons between two systems and their functionality using SUS; It does not provide a precise basis of action.

3.4   Validation of Mobile Farming as a Business Via Benchmarking Framework through Design Science Research

The research methodology for this DSR was evaluated against seven guidelines suggested by Hevner *et al*. (2004). These guidelines were proposed for the purposes of assisting researchers, reviewers, editors, and readers in understanding the requirements for effective design science research. Table 4 summarizes the seven guidelines.

Table 3: Design Science Research Guidelines

Guideline	Description
Guideline 1: Design as an Artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Search Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Hevner *et al.* (2004)

3.5 Summary

This chapter has developed and justified a research methodology adopted for the presented research. The DSR paradigm was considered, selected, customized and deployed as the research methodology, which is an appropriate approach to investigate problems in the Information Systems domain (Hevner *et al*., 2004). Supplemented with the SSM research process model (Bergvall-Kåreborn *et al*., 2004), (described in Section 3.2), the DSR paradigm outlines the research activities, ensures a rigorous research process, and presents a complete research methodology (Peffers *et al*., 2006). Also presented is the justification of why SUS was adopted as the rightful methodology to test the usability of the prototypes that were developed based on the principles of m-FFAABB.

CHAPTER FOUR

RESULTS AND DISCUSIONS

4.1 Results

4.1.1 PART 1: Mobile Framework for Farming as a Business via Benchmarking Business Logic Design

In this chapter, the m-FFAABB business logic is proposed based on the FAABB decision process, and therefore, addresses the five stages: domain recognition, product characterization, farm management, limiting factors control, and post-production evaluation stages (Sec 2.1). The m-FFAABB business logic specifically aims at addressing the challenges faced by EOs in facilitating their farmers at individual stages of FAABB, and it is intended to facilitate the development of mobile information systems for the whole decision process by providing crosscutting FAABB services.

The proposed m-FFAABB business logic includes twelve components that support the FFAAB decision process, as shown in Fig. 9 including: (a) value chain vocabulary, (b) product defining factors, (c) the GEG generator, (d) farm configuration, (e) event manager, (f) production management, (g) constraint management, (h) resource utilization, (i) farm productivity, (j) farm profitability, (k) knowledge codifier, and (l) data collector. On the basis of functionality, these components are classified into two main types: facilitating and unifying components.

A facilitating component targets an individual stage of the FAABB decision process to help farmers complete the stage effectively and efficiently. A unifying component is responsible for integration and coordination among the facilitating components. Each component was suggested based on the corresponding identified studies in the literature, as listed in Table 4 and various discussions with experts through SSM iterations. Due to the modular approach of the study, it was possible to allow incorporation of existing work in the literature into the framework, as well as extensions of the framework by adding new components proposed by stakeholders at various workshops.

The ten core facilitating components are described in the following subsections, followed by descriptions of the two unifying components. Table 4 illustrates these components as well as data sources, and the data exchange among them.
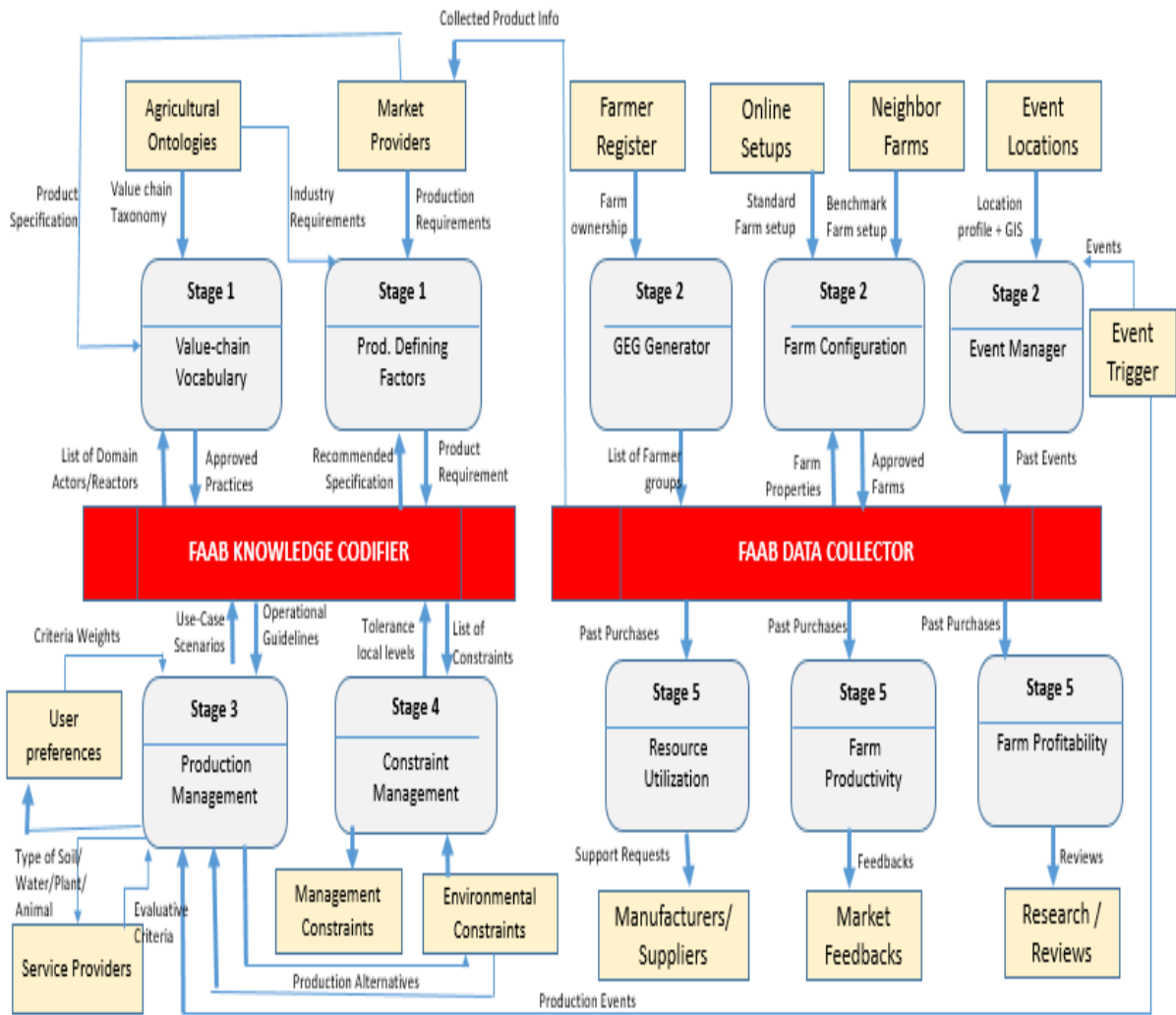
Figure 9: Components of the Mobile Framework for Farming as a Business via Benchmarking Business Logic

Table 4: Farming as a Business via Benchmarking Components and Justifying Studies in the Literature

Component	Assisted FAABB Stage	Justifying Research
Agricultural Ontology	Domain Recognition	Jebaraj and Sathiaseelan (2017), Hernandez *et al.* (2017) and Antonopoulos *et al.* (2014)
Product Defining Factors	Domain Recognition	Saiz-Rubio and Rovira-Más (2020), Ferris *et al.* (2014), Maendeleo Agricultural Technology Fund (MATF, 2009) and Maschinen *et al.* (n.d.)
Farm Configuration Generator	Product Characterization	Dodds *et al.* (2019), Nyambo *et al.* (2019) and Lambin *et al.* (2000)
GEG Generator	Product Characterization	International Finance Corporation-World Bank Group (IFC-WB Group, 2016), Department of Agriculture Forestry and Fisheries (2012) and Cuddeford (2013)
Event Management	Product Characterization	Salokhe *et al.* (2008), Saiz-Rubio and Rovira-Más (2020), Martin *et al.* (2011) and Antonopoulos *et al.* (2014)
Farm Production Management	Farm Management	Accenture (2013), Dodds *et al.* (2019) and Antonopoulos *et al.* (2014)
Constraints Management	Limiting Factors Control	Dodds *et al.* (2019) and Martin *et al.* (2011)
Resource Utilization	Post Production Evaluation	Accenture (2013)
Farm Productivity	Post Production Evaluation	Dodds *et al.* (2019) and Fermont and Benson (2011)
Farm Profitability	Post Production Evaluation	Cachia (2017)

(i)   Components for the Domain Recognition Stage

The domain recognition stage is facilitated by two main components; the agricultural ontology generator component and the product defining factors component.

Agricultural Ontology Generator Component

In many cases in the SAGCOT areas, there are well established markets for agricultural products but farmers are struggling to meet the market demands due to lack of production knowledge particularly for new products with the potential for good profit margins.

Ontologies have played a vital role in the field of agriculture. The agriculture domain is a vast and complex system science and the knowledge of it consists of many concepts and relationships. These difficult concepts and relationships have been modelled using Ontologies in various capacities in different countries. A review of the various ontology-based applications developed specifically for the domain of agriculture is presented by Jebaraj and Sathiaseelan (2017). The authors in this work also discuss various agriculture ontologies created by specific developing countries.

The ontology generator component of m-FFAABB generates the required value-chain structure to help the EO in the domain recognition stage (Hernandez *et al.*, 2017). The value chain structure templates are delivered through the mobile phone of the EO to help in selecting a needed production base. Briefly, this component periodically checks the location of the farming, the crops or animals to be encouraged for farming, and markets that require their typical farm products. If the current description of the farming matches the requirements of a market, the component shows a parameterized template to the EO, showing, for example, the type of seedling required, size of the farms, and soil structure needed to grow the crop.

Product Defining Factors Component

The essence and need for having a product defining factors component is well articulated and amplified by Saiz-Rubio and Rovira-Más (2020). On the one hand, farmers understand their agricultural production domain very well and need only to identify the markets that can purchase their products at better prices. Mobile questionnaire held by EO may initiate the farming decision process by emulating the basic properties of their product based on the information obtained from the ontology generator and seek for the markets that are interested in the product.

On the other hand, it is possible to stimulate farmers interest for certain farm products through market offers. Once the market is known, its preferences are retrieved by EO, then the benchmarking is performed to evaluate as to what extent the market requirements can be met by the farmers.

Defining factors component aggregates farm/product profile and location information and, in turn, provides a mobile generated market enquiry. Therefore, this component periodically looks for a match between location and time based offers of EO and the location of the agro dealer of chosen products in the list of available market offers. The component reports a mismatch between required properties (that define market preferences of product quality and quantity) and market the corresponding offer to the EO.

(ii)   Components for the Product Characterization Stage

After an awareness of need has been built about the product needed, EOs pass to the second stage of the FAAB decision process, farm characterization and management. The EOs take actions to obtain farm selection knowledge in this stage. On the one hand EOs search for information about previous experiences regarding the farms, information obtained from past farming arrangements, and information collected from farmers' recommendations. However, EOs have intellectual limitations to recall information from their memory. On the other hand, EOs look for additional information such as neighboring farms from other Agriculture Marketing Cooperative Societies (AMCOS) networks, and agro-dealer-dominated sources such as web sites.

Three components described next facilitate the farm characterization stage by collecting the required information, reducing information overload, and presenting related and filtered information for farm selection. These components also address the challenge of intellectual limitation of EOs to recall information, by presenting previously recorded farm information.

Farm Configuration Generator Component

In farm configuration generator, EOs recall farm parameters and their previous configuration (Dodds *et al.,* 2019; Nyambo *et al.,* 2019; Lambin *et al.,* 2000). Therefore, in order to help with farm characterization, previous parameters and activities of the farming are recorded, and relevant recorded information is recalled when the EO needs it in the next production cycle. These activities include past seedling, previous product comparisons, and experiences with farm resources such as soil treatment, and pest control mechanism.

The farm configuration generator component facilitates the localized process of recording the history of all activities such as type of seedling, comparisons and reviews of the resources applied to the farm and their costs, and recalling these records when the EO needs them. The outcome of this component is a setup of the benchmark farm based on the previous productions.

Grassroots Economic Groups Generator Component

Farmers need to be well organized to compete in an increasingly demanding marketplace. Like becoming a crop specialist, joining a farmer organization is a necessary step for small-scale farmers who want to increase their income and capture more value in the value chain. Unlike individual farmers, farmer organizations have the resources to attract and build relationships with different links in the value chain, both locally and further afield (Cuddeford, 2013).

Managing FAAB for smallholder farmers requires the attainment of economies of scales either through one village one product configurations or via block farming. Recent recommendations in the literature recommends community based farming through self-organized grassroots economic groups (GEGs) around each product (International Finance Corporation-World Bank Group [IFC-WB Group], 2016). A good insight into the value of mobilizing GEGs is provided by IFC WB Group (2016), and Department of Agriculture Forestry and Fisheries (2012). This entails collection of profiles of farmers and their respective farm blocks within a big farm that is managed by a dedicated EO and their locations. For smallholder farmers it is important to separate between the farm block owner (who are, in most cases, heads of the family) and the farm employees (who are, in most cases, family members of farm owners).

The GEGs generator component collects farmers' demographic information through a mobile phone and validates them through recognized external databases like National ID database. It also collects biometric and geo information of their farms and validates them through GIS applications.

Finally, the GEGs generator component attaches each farmer in a GEG to an associated bank account through which all earnings and expenditures will be traced. For example, Unilever Co. Ltd (Sutton & Olomi, 2012), has developed a farmer registration system to manage individual farm blocks within a large farm by linking them to the warehouse receipt system and matching a farmer with a his/her bank account. The outcome of this component is a

profile of farmers (*as investors on the farm*) through which all farm costs and earnings will be legally associated. The outcome of this component is a list of farmers whose farm blocks meet the selection to be included as part of a larger farm.

Event Management Generator Component

A critical aspect of achieving FAAB is for the farmers to understand "*How-to-leave with the crop/livestock*". It is critical that all events necessary for the production process are properly and timely undertaken. Utilizing the EO to trace information regarding event management in the presence of many farmers in a GEG can increase EO's sense of uncertainty. According to the theory of information overload (Jacoby *et al*., 1974), the EO may spend more effort and time to process information and may make lower quality decisions in case of information load increasing beyond a threshold. Research shows that information overload results in less satisfied, less confident, and more confused EOs (Jacoby, 1984).

Event management component facilitates handling of event oriented information overload, by aggregating heterogeneous events information sources, and presenting the results to the farmer in a personalized calendar (Nell *et al.,* 2014; Lambin *et al.,* 2000; IFC WB Group, 2016). Consequently, each farmer within a GEG has an electronic calendar of events to track throughout the production cycle. Once the event calendar is electronically managed, the EO gets reminded through a mobile phone on what each farmer needs to do on a specific day and time and makes a follow-up.

The event manager component in m-FFAABB is intended to collect and retrieve information for all role players regarding the critical events within the lifecycle of the FAABB process. Non-controlled sources are modelled as limiting factors (in Stage 4), which include weather disruption, attacks by external insects, and other events that are not associated with predetermined production factors, whereas controlled sources include events information generated by agro-practices. The event manager component classifies controlled and non-controlled events, and presents filtered information according to date/time stamp and role player.

(iii)   Components for the Farm Management Stage

Components in the farm managements stage should assists the EOs to link up properly with dealers of farm inputs, service providers and researchers to manage the farm during its production. The EOs continues to follow traditional farming practices because they lack

access to knowledge about current practices. Living in remote areas of the world, struggling to nurture crops on tiny plots of poor land, they overuse macro fertilizers and miss the benefits they could gain from micro-fertilizers and alternate cropping appropriate for their crops and soil. On the one hand, they also lack a scientific understanding of pest life cycles, and thus often experience crop failure when a preventable infection or infestation arises (Dodds *et al.*, 2019). On the other hand, they also lack knowledge of the alternate crops required for seasonal rotations or co-existence of crops/livestock (Martin *et al.*, 2016).

The farm production component connects these three stakeholders in rural agriculture (i.e. the EO, agro-inputs companies and farmer) in order to improve agent productivity, product sales, and farmer crop's yield. The component helps farmers identify the inputs that best match their expectations among available alternatives. Accordingly, it enables prescription of relevant inputs according to their farm application procedures and standard criteria.

In the absence of any limiting factors, the farm production component links up to four key sub-components which provides specialized benchmarking tasks as follows: Determining the soil structure, deciding the type of plant/grass/breed seedling, identifying the right inputs and services, and determining the amount of water required for the optimal production. In some system setups, these subcomponents could be modeled as independent components by themselves (Dodds *et al.,* 2019; Department of Agriculture Forestry and Fisheries, 2012).

For example, a soil subcomponent determines soil characteristics, which reflect features or characteristics markets are interested in. It is preferable to have the soil structure differentiated according to the product category (e.g. evaluative soil criteria of an organic crop and inorganic crop are different). Hence, the component incorporates evaluative criteria according to the category of the product. Value chain taxonomies and ontologies provide the means to address the challenge of determining the appropriate characteristics and input values.

(iv)   Components for the Limiting Factors Control Stage

Once EOs identify the farm input requirements, they continually subject a particular production farm to locally known constraints to obtain realist production levels (Martin *et al.,* 2011; Dodds *et al.,* 2019). Assistance regarding the constraint based modeling in FAABB is typically a function of optimization equation for farming decision support

system (Filatovas & Kurasova, 2011). In practical terms, EOs need to consider at least five production constraints as part of their consideration of limiting factors for production optimization. These are resource availability, local policies and management practices, reducing factors (Donatelli *et al*., 2017), (e.g. weeds, pests, diseases, etc.), climate/timing, and market decisions.

The proposed component for this stage assists EOs evaluate the impact of each of the constraint on the farm and proposes the adjustments to the farm inputs/services list produced by the farm production component. Therefore, this component provides recommendations by combining information regarding the simulated farm profile (from production simulation stage), and downgrade them through the application of constraints levels enforced by the limiting factor.

The constraint manager component also supports this stage by linking it to global forecast service providers and local institutions to provide information and updates related to weather forecasts and market information in order to facilitate modeling decisions.

(v)   Components for the Post-Production Evaluation Stage

After harvesting the product (or achieving a major milestone in between), the EO begins to evaluate the farm performance during production. Depending on the relationship between the expectations of the farming at the planning stage and perceived performance of the production, the outcome of post-production evaluation stage is satisfaction or dissatisfaction. This stage determines whether the farmer makes a complaint, decides to farm the same product again, talks favorably or unfavorably about the product with others. Moreover, production satisfaction is a critical factor on farmers' intentions, even with regard to farming an alternate crop (Padmavathy & Poyyamoli, 2011).

As part of m-FFAABB, the following three components are proposed to facilitate post-purchase evaluations of farms: resource utilization, farm productivity and profitability.

Resource Utilization Feedback

Investments on farm resources and services significantly influence the farm production (Accenture, 2013). The resource utilization feedback component facilitates the post-purchase evaluation stage by providing an interface to review and share complaints, satisfactions and reviews related to the availability, effectiveness, affordability, and delivery of all necessary and planned farm services to farmers.

Farm Productivity Feedback

Correct agricultural statistics are essential for planning and evaluation of agricultural investments to improve the productivity and profitability of smallholder farming systems (Cachia, 2017). However, accurately estimating crop yields is never easy and is even more of a challenge in the context of rural farming systems that are characterized by smallholder farms that produce a wide range of diverse crops (Dodds *et al.*, 2019).

Therefore, a feedback mechanism where farmers express their level of satisfaction or dissatisfaction with a particular product quality and quantity levels per production is mentioned as an influencing factor of the post-purchase evaluation stage (Fermont & Benson, 2011).

The farm productivity feedback component enables buyers to directly share their feedback with product producers so that farmers can improve on their practices in the next FAAB round. This component also provides benefits for product buyers, since farmers feel more engaged with products if they are able to receive feedback about them for improvements.

Farm Profitability Feedback

This component provides a communication interface between farmers and service providers or vendors to enable a support mechanism through government subsidies or loyalty programs (Cachia, 2017). The EOs can send a relief support request to the vendor or manufacturer using this module, and check the status of the request. For example, through the use of warehouse receipt system, farmers can negotiate interest free loans, or bulky procurement of farm services as a way of reducing expenditure and optimizing profit. This component can compare the sales of a particular season with the liabilities recorded in the ware house receipt system to compute the profitability levels and propose the appropriate bail-out intervention.

(vi)   Unifying Components

The knowledge codifier and the data collector components are the unifying components of the proposed framework that are associated with all stages of the farming decision process. Compared to other studies, these components are significant, since they enforce the holistic nature of m-FFAABB by enabling   information flow among all the components, as well as providing integration and orchestration of them.

Farming as a Business Knowledge Codifier

Codification of agricultural information is an important asset for successful FAABB (Zecca & Rastorgueva, 2017). In this study, the FAABB repository for m-FFAABB is essentially an effective external memory storage mechanism for m-FFAABB that was decided to be hosted by NM-AIST through CREATES for the reasons amplified in Section 4.7. Therefore, the codification of benchmarking knowledge and its management through a dedicated external entity like CREATES is a crucial factor for supporting long term development of m-FFAABB for a sustainable ARD.

Discussion with the EOs in the filed indicated that between 60% and 85% of EOs prefer to use a formal benchmarking practice rather than informal benchmarking. However, the majority of EOs in rural areas are still using inferior and ad hoc farming practices (Zecca & Rastorgueva, 2017).

Research studies related to knowledge-intensive business services (KIBS), indicates that a suitable knowledge management strategy requires a codified information based on a standardization method. Standardization can refer to the way the creative effort is organized and managed internally through appropriate organizational processes, with the approach confirmed empirically (Bettiol *et al*., 2012).

The FAAB knowledge codifier component is not just a form of a stored farming data elements; it also provides additional capabilities. While the EO follows the stages of the FAABB decision process, this component establishes an interface with other components, and carries information between the stages.

For example, the product defining factors component adds product requirements to the FAABB knowledge codifier in the domain recognition stage, and then the EO gets information about these products in the limiting factors stage. After that, the EO evaluates productivity based on the same factors and stores a copy of the report in the knowledge codifier component in the post production evaluation stage. Once the post production evaluation stage is completed, the production analytical reports are recorded as part of past farming experiences in the FFAAB knowledge codifier. As seen in this scenario, reports produced in one season are made available and utilized in the following seasons, through the use of the FAABB knowledge codifier.

In the absence of external benchmarking service provider, this component suffers from the storage space requirements. As a result of exponential growth of knowledge and information to be codified there is a huge pressure for mobile application developers to individually invest on huge data infrastructure. It also suffers from cost of requiring additional knowledge hosted by disparate servers, most of which require membership or provided at cost.

Farming as a Business Data Collector

The data collector component provides data flow among proposed components of FAABB. It gathers data from components and provides data for them, such as farm characterization information, event information, soil data, weather data and farmers' names in a GEG. The data required by the components are collected implicitly or explicitly. The implicit data collection is collecting data while the user is interacting with the system in an implicit way. In this method, the system captures data while observing the activities of a user. For example, the selection of a product to engage in for a particular farming season can be identified using the historical data of this GEG; if the GEG always farms maize, this finding implies that previous season buyers and service providers are the most preferred ones for this crop.

In the explicit data collection, the user gives the required data in an explicit way. For example, asking EOs to input their preferences for selecting farm services and market providers is an explicit data collection activity. The data collector uses different input methods, such as mobile electronic questionnaires, barcode scanning, GIS devices and IoT for data collection.

Again, in the absence of external benchmarking service provider, this component suffers from the storage space requirements. As a result of exponential growth of data to be exchanged there is a huge pressure for mobile application developers to individually invest on huge data infrastructure. It also suffers from cost of requiring additional data hosted by disparate servers, most of which require membership or provided at cost.

4.1.2 PART 2: Mobile Framework for Farming as a Business via Benchmarking External Benchmarking Services

The essence of external benchmarking is to learn how to achieve excellence, and then setting out to match and even surpass it. The justification lies partly in the question: *Why reinvent the wheel if I can learn from someone who has already done it?* (Dragolea, 2009). The answer to

this question opens doors to *external benchmarking*, an approach that is accelerating among many firms that are engaged in ARD.

As data intensive handlers, external benchmarking require shared infrastructure not only for the purposes of "big-data" handling through a specialized data warehouse or "cloud-computing services", but also a pool of domain experts and specialists that provide backstopping services for data modeling and benchmarking as a "shared human resource" to the wider community.

As mentioned in Section 2.2, the benchmarking approach is realized through knowledge codification and consists of four phases: Collect, analyze, share, and actuate. In the collect phase, gathered data by EOs are sent by their respective m-apps server to m-FFAABB server at NM-AIST via API, and stored in the respective server component. In the analyze phase, the collected data are analyzed in m-FFAABB servers and the results are staged in the respective component. Then, in the share phase, analyzed data are pushed to m-app server through the same API and subsequently produce results on EOs phones. In the actuate phase, the API can trigger actions to be taken by mobile apps for supporting EOs' decisions.

Therefore, NM-AIST through CREATES provides external benchmarking services to empower m-FFAABB by providing comparative analyses required by each component of the framework and enable new functionalities, as described in the following sections.

(i)   Information Architecture for External Benchmarking

In order to utilize the benefits of the external benchmarking services, the m-FFAABB external benchmarking services for m-FAABB at NM-AIST has been designed such that it is compatible with each phase of the m-FFAABB business logic. Consequently, components of the information architecture for external benchmarking services at NM-AIST is a three layered framework, designed as replicas of: (a) the five business process components, (b) the knowledge codifier components, and (c) data collector components.

As shown on Fig. 10, external benchmarking services will complement the m-FFAABB business logic activities: (a) Collecting or providing missing data for completing an external benchmarking activity (b) Storing or retrieving a codified information to facilitate completion of internal or external benchmarking activity, and (c) Conducting an external modeling or analysis to complete an external benchmarking activity at a particular FAABB stage.

In the following subsections, each component of the m-FFAABB Business Logic is described in terms of the phases of the external benchmarking approach to show the compatibility of the component with this approach. Benefits of external benchmarking are explained for each component
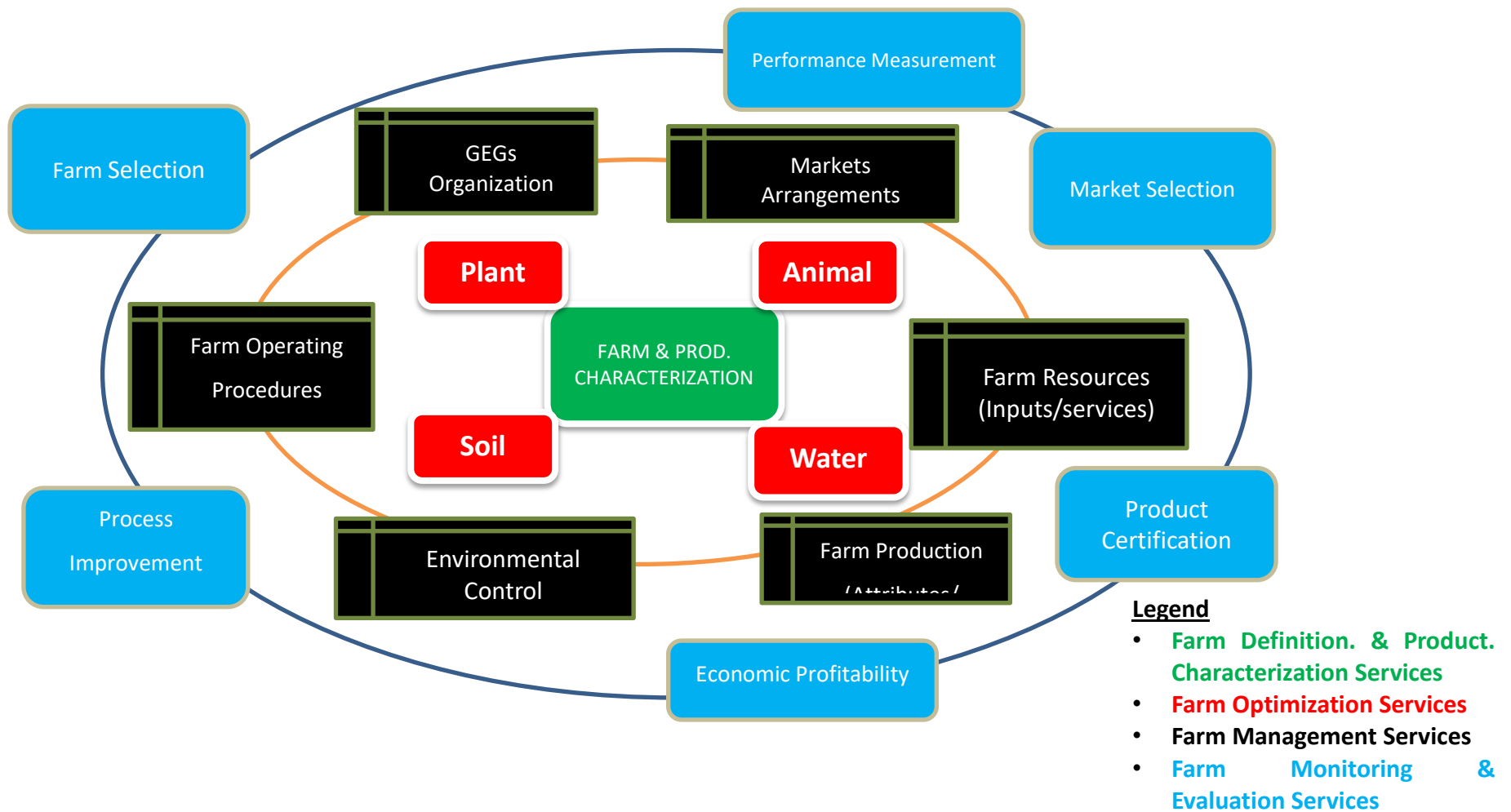
Figure 10: Information Architecture for External Benchmarking at NM-AIST

Domain Recognition

- **Compatibility with External Benchmarking**

This component assists the EO to understand a needed product and its market dynamics from a global perspective. The EO identifies the farming location parameters and the type of business farmers want to engage-in within the settings of their environments. In the collect phase, the product to be invested in, the preferred location for the producer, and the production seasons data are sent to m-FFAABB server at NM-AIST. Then, the ontology component at the server side analyzes the current context (the location and time) of the farming, and compares with codified ontology instances as well as the potential market preferences. If the component finds a match between the EO's context and a global ontology, it shows a parameterized message to the m-app server in the share phase indicating the appropriate value chain for particular product of choice. After that, the m-app server recognizes the domain, which is the preferred product and its potential market and service providers and displays the same to the EO phone.

- **Benefits of External Benchmarking**

The external benchmarking approach contributes a new functionality to the domain knowledge recognition component, which is the collaborative ontology building concept. In this concept, an off-taker can share the production requirements with m-FFAABB server at NM-AIST to request for a product supplies from farmers at the intended season and location. The benchmarking models further use value chain taxonomies from the agricultural ontology databases of m-apps servers to validate the needed actors in the production and their roles.

Farm Characterization

- **Compatibility with External Benchmarking**

In the collect phase, the farm characterization component obtains information about the GEGs, their farm to be invested on, and critical events from the EO. In the analyze phase, this component periodically requests m-FFAABB servers at NM-AIST to analyze the current context and the collected farm setting of the EO, and compares them with the settings offered by potential similar farms that were codified by m-FFAABB servers at NM-AIST through previous farming cycles or collected by CREATES researchers as part of their big-data project. If there is a match between the compared farms, this component

shows corresponding farm set-ups to the m-app server in the share phase. Then, the m-app server recognizes common farm properties, GEGs settings and critical production events for particular products, and advises EOs to select farmers to engage in these products in the actuate phase.

- **Benefits of External Benchmarking**

The external benchmarking service brings two new features to this component. The first one is the collaborative characterization feature. Using this feature, an EO can share successful farm characterization for a specific product with CREATES experts. Then, another EO can request the same characterization from the system for as external farm similar to this EO. The shared characterization includes general information about the typical farm size, the product type, the type of contract GEGs engaged in with the markets, and the necessary events for production.

The second feature brought by external benchmarking approach is the collaborative procurement planning feature. Through m-FFAABB API implementation, the EOs, who want to request farm services for a specific production, can collaboratively utilize the same service provider (who happen to have supplied to a similar farm) and avoid additional overhead costs of recruiting farm service provider. It is a similar concept with the "shared services procurement", which is embracing the utilization of local experiences to avoid surprises that are brought about by new comers in providing services to farmers.

Farm Production Simulation

- **Compatibility with External Benchmarking**

In the collect phase, the production management component gathers the farming inputs and services necessary for the farming including soil testing, choices for seedling, farmers' preferences and their purchasing power, farm input prices, storage charges, and multiple purchases and sends this information to m-FFAABB server at NM-AIST. Then, in the analyze phase, m-FFAABB server at NM-AIST uses this component to undertake optimization algorithms from CREATES to find the most cost-effective means for service acquisition and payment possibilities. It embraces the concept of "bulky procurement (i.e. collaborate with other farmers' groups to jointly procure farm inputs/services generate an adequate volume of orders to create the basis for a lower transaction cost to individual farmers). It presents the cost effective procure -and -store scenarios to the EO in the share

phase, and the farmers make the service-provider and payment-method decisions in the actuate phase.

- **Benefits of External Benchmarking**

Utilizing the external benchmarking approach, a procurement strategy and operational guidelines used by most GEGs for a specific product can be recommended to new request by the EO. This component can automatically adopt use-cases from farmers' preferences, or an EO can manually share the farm management scenarios using the framework through m-FFAABB API.

Limiting Factors Control

- **Compatibility with External Benchmarking**

The limiting factors component gathers the constraint factors on the farm, such as weather patterns and reducing factors (such as weed, pests and diseases), in the collect phase. A constraint includes information about the current values of the limiting factors supplied by an EO or IoT.

In the analyze phase, at CREATES, constraint levels are analyzed for their potential positive or negative effect to respective parameters of the farm management scenarios in a standardized environment. For example, the rain patterns being recorded are comparable to the previous production seasons and how is that likely to affect the farm soil and water contents, may require CREATES to connect to weather forecast service provider to retrieve data.

Then, in the share phase, this component shows the typical production management parameters in the presence of these constraints. Since the collected information is related to local activities, it is used to perform the internal change management task in the actuate phase (e.g. trigger water additions through irrigation schemes or undertaking liming on the existing soil).

- **Benefits of External Benchmarking**

Without external benchmarking, environmental constraint data for this component can be very expensive to collect and analyze just for the sake of serving a single farm by the EO who collects the data. However, utilizing the external benchmarking approach, this data can be used to bring new functionalities to the system. For example, the system can use diseases

found in a typical farm to identify neighbor farms that are likely to be affected by the same disease for collaborative treatments, and recommend the pesticides killers they would like to purchase for such treatments.

Post Production Evaluation

- **Compatibility with External Benchmarking**

In the collect phase, the EO acquires reviews related to a product from market sources, such as local vendors, current off-takers, service providers, and onsite visits to specific products. Then, in the analyze phase, this component analyzes collected information to find the relevant reviews about the current productivity and/or profitability relative to industry best practices. In the share phase, the evaluation component shows the relevant evaluations/reviews to the EO. In the actuate phase, the EO performs the change management activities for the next production cycle.

- **Benefits of External Benchmarking**

Without the benchmarking, this component only provides reviews collected from market sources. However, the benchmarking approach enables sharing of review reports with other stakeholders. In addition, comparative analysis of different product performances by NM-AIST analysts provides average scores for the product, which serves as a traceability tool for product certification and branding.

Farming as a Business Knowledge Codifier

- **Compatibility with External Benchmarking**

In the collect phase, the knowledge codifier component gathers potential reports from internally controlled and external non-controlled sources of relevant information. Then, in the analyze phase, this component classifies formal and non-formal knowledge, and filters the knowledge that can be stored for use in the future by other stakeholders. In the share phase, the knowledge codifier component presents filtered information to the stakeholder in a personalized manner. Finally, in the actuate phase, the EO performs an external match-making of the farmers' experiences to the potential markets using the presented information and updates the ontologies.

- **Benefits of External Benchmarking**

Utilizing benchmarking approach, the knowledge codifier component also collects data produced by other participants as non-controlled sources. In addition, the benchmarking approach enables simultaneous interaction with other EOs to search information. For example, an EO can ask opinions about a product to another participating EO by using this component.

Farming as a Business Data Collector

- **Compatibility with External Benchmarking**

In the collect phase, the data collector component at m-FFAABB server at NM-AIST obtains inputs from IoT. These inputs include the type of data gathered and its intended component (sub component) within the FAAB process. Then, in the analyze phase, this component uses decision rules to generate a ranked match of alternatives. In the actuate phase, the EO chooses to or not to use it.

- **Benefits of External Benchmarking**

The benchmarking approach enables the collection of the required data for the multi-GEGs process recommendation component. For example, prices and features of farm inputs can be collected through benchmarking. In addition, the benchmarking approach enables the collaborative control of limiting factors through centralized data capture, which uses IoT through other researchers external to FAAB projects. Moreover, this approach enables simultaneous interaction with other EOs to collaboratively evaluate intervention alternatives, similar to group decision-making. Table 5 summarizes the components of the m-FFAABB framework for external benchmarking.

Table 5: Components of the Mobile Framework for Farming as a Business via Benchmarking-Benchmarking Services

Component	Collect	Analyze	Share	Actuate
Domain Recognition	EO uploads current scenario of the product specifications in both quantities and quality estimates as well as minimum price per unit	Whether the current context of the farming matches with the industry and market standards	Shows a best practice message to the EO and a list of companies ready to buy	The EO recognizes the domain and convinces farmers to engage in the production
Farm Characterization	EO uploads basic farm details including farm owners, size, primary product, secondary product, geo locations, seasons, climatic conditions, etc.	Whether the current farm specification matches *benchmark or similar farm setup* elsewhere with the same climatic conditions	Shows *all critical events* necessary for the production of the preferred primary and secondary products + contact of benchmark EO	The EO agrees with farm setups and selects GEGs whose farmers can *invest and play necessary roles*
Farm Production	EO uploads the farm details incl. type of crop plant /livestock, pests, and need for soil testing; and provides test samples to the testing lab at CREATES. The test	Whether the test results of soil and pests submitted to the system by CREATES *deviate from the standard interventions recommended levels* for liming,	Shows personalized reports with advice on nutrients and pesticides to apply on the farm.	The EO meets with the inputs /service providers and GEGs to agree on the interventions and
Limiting Factors Identification	EO tracks and uploads time-stamped farmers' status, crop progress, existing levels of limiting factors to the system	Whether the effects of limiting factors *affects farm progress positively or negatively* based on the expected outcomes from input providers recommendations.	Shows additional Intervention levels required	EO meets with the farmers and service providers to discuss and agree on the recommended interventions

Component	Collect	Analyze	Share	Actuate
Post Production Evaluation	EO tracks and uploads farmers status on crop yield to the system and assist farmers to transport the product to the market	The system computes each farmers sales and analyses productivity, profitability, and resource utilization levels.	Shows the Graphs and tables on performance measures	The EO meets the farmers and persuade them to continue farming or make some changes.
Information Aggregator	Input suppliers and market providers submit progress reports of their farmers to the system	Classify and filter collected data and provide aggregated comparative reports across multiple EOs and GEGs	Shows relevant product information	The funders and researchers are activated to intervene
Data collector	CREATES collects relevant product taxonomies, their recommend production models and inputs from IoT	Test the relevant *benchmarking models* and their assistance in FAABB decision making	Shows a ranked list of its utility in FAAB	The EO chooses the final results

(ii)   Proposed Application Programing Interface Framework for Data Exchange

Realizing the benefits of external benchmarking will require frequent data exchanges between CREATES server and applications that are going to be developed by various m-apps developers. Capturing and exchanging supplementary knowledge or data between CREATES servers and m-apps developers (as web clients) will require data exchange framework. The RESTful API through the Java Script Object Notation (JSON) was selected and adopted as a framework to enable data exchange between the m-FFAABB remote server(s) and respective web clients.

A "RESTful" application is typically one that uses standard verbs like get, post, put, delete, and so on to retrieve and send data to and from a remote server. The RESTful applications use universal resource identifiers (URIs) pointing at resources (objects that contain data) to interface with external systems such as a remote server, and uses verbs to perform operations on those resources on the server either retrieving data, creating new data, or changing the data in some way.

In the m-FFAABB RESTful API, that data comes back as JSON, which is an open standard format that is used to transmit data objects in the form of attribute-value pairs for further processing. The JSON is commonly used for asynchronous communication between browsers and servers, the kind of communication performed by RESTful APIs and is favored over XML because it is cleaner and easier to work with. So, if all of these are put together, the m-FFAABB REST API is a RESTful API for m-FFAABB that returns data objects in the JSON format when provided with URIs pointing at a resource. The proposed JSON based RESTful API for m-FFAABB prototype is presented in Appendix 1.

The m-FFAABB framework is built on a modular approach that allows incorporation of existing work from the literature into the framework, and extension of the framework by adding new components. The framework extension points are defined so as to provide extensibility of the m-FFAABB framework. These extension points include common tasks that new components have to extend for providing new functionalities to the framework as well as extending functionalities of the existing components.

Similar to the component classification of the m-FFAABB framework, the framework extension points are classified into two main types on the basis of functionality: stage extension points and unifying extension points. A stage extension point includes a common task that a new component has to implement for extending the framework for an individual

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stage of the FAABB decision process. The stage extension points are based on the identified models for each stage in the literature. For example, *"SimulateSoilStructure"* and *"SimulateCropStructure"* and *"SimulateAnimalStructure"* are the stage extension points of the production simulation stage of the FAABB production management stage. Any one of them can be implemented as a new component dedicated for the farm management stage. The identified stage extension points, corresponding stages, and brief descriptions of their functionality are listed in Table 6.

The unifying extension points are responsible for integration of a new component with the unifying components. At least one unifying extension point has to be implemented to define interconnection of extension component with the unifying components. Then, the unifying components can provide integration of this component with the existing components. Table 7 lists the proposed unifying stage extension points, the corresponding unifying components, and brief descriptions of their intended functionality.

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Table 6: Mobile Framework for Farming as a Business via Benchmarking Stage Extension Points for External Benchmarking

Stage Extension Point	Stage	Description
CropOntology	Domain Recognition	Creating a Taxonomy for Crop value chains
CropMarketSelector	Domain Recognition	Select the off-taker to purchase the Crop products
ImportAmcos	Product Characterization	Crete an AMCOS registered GEG
ImportBrela	Product Characterization	Create a BRELA registered GEG
SimulateSoilStructure	Farm Management	Determine Soil evaluative criteria and acceptable levels
SimulateCropStructure	Farm Management	Determine crop evaluative criteria and acceptable properties
SimulateAnimalStructure	Farm Management	Determine the herd type and characteristics for the production
SimulateWaterLevels	Farm Management	Determine water levels and acceptable levels to sustain the farm
LogisticalContraints	Limiting Factors Control	Determine the cost effective transportation roots
PostHarvestConstraints	Limiting Factors Control	Estimate the loss caused by postharvest handling
StorageConstraints	Limiting Factors Control	Estimate the effect of storage limitations
PestsConstraints	Limiting Factors Control	Estimate the effect of pesticides to the production
WeatherConstraints	Limiting Factors Control	Estimate the effect of weather to the production
LoanManagement	Post-Production Evaluation	Managing Loyalty Farmers' Programs
ProductCertification	Post-Production Evaluation	Evaluate product quality for given a market segment

Table 7: Unifying Extension Points for External Benchmarking

Unifying Extension Point	Unifying Component	Description
InsertItem	FAAB Knowledge Codifier	Adding a new knowledge item to the FAAB knowledge codifier
DeleteItem	FAAB Knowledge Codifier	Removing a knowledge item from the FAAB knowledge codifier
PullData	FAAB Data Collector	Requesting data from the data collector
PushData	FAABB Data Collector	Sending data to the data collector

4.1.3 PART 3: Mobile Framework for Farming as a Business via Benchmarking Ready Prototypes and Test Results

Two mobile application prototypes were designed and implemented based on m-FFAABB through client server architecture. They were deployed based on different data storage platforms and tested on different Android mobile phones such as Samsung Galaxy S8 and Techno Spark. They were also implemented based on different infrastructure setups. One prototype was for case study I (Crop production use-case) and the other one was for Case study II (Dairy production use case) as introduced in Section 3.3.

As shown in Fig. 11, the two prototype systems were configured based on a common client-server architecture consisting of a mobile application that includes developed modules, a back-end server that runs the server application, and a database server that includes the databases. The mobile application can access the mobile device services; for example, the camera service to provide the farm coordinates for the GIS function, and the local database to cache data. The mobile application communicates with the back-end server over the mobile device's network connection to exchange information directly or through cloud computing. The back-end server accepts requests from the mobile application, processes them, and sends these queries to the database server. After that, the database server sends the requested data to the back-end server to be delivered to the mobile application.
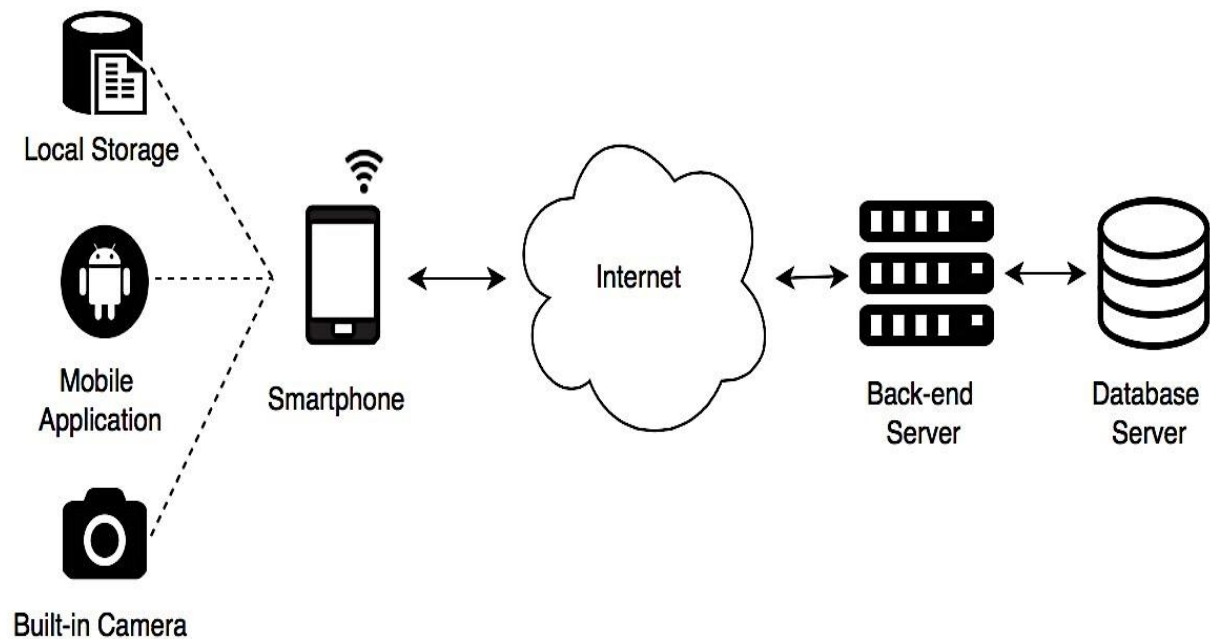

Figure 11: Client-server Architecture of the Prototypes

(i)   Case Study 1: The Crop Production Use Case

The first case study was an instantiation of the m-FFAABB based on crop production business logic and use case scenarios.

The System Setup and Development Infrastructure

Figure 12 presents the architecture that was adopted by the first company that was selected by SAGCOT to pioneer the realization of the m-FFAABB in the crop subsector. The company embraces the open source software development based on NoSQL database platforms.

The system was developed and deployed based on Infrastructure-as-a-Service ("IaaS"), which is a form of cloud computing that delivers fundamental computing, network, and storage resources to consumers on-demand, over the internet, and on a pay-as-you-go basis. In an IaaS model, a cloud provider hosts the infrastructure components traditionally present in an on-premises data center, including servers, storage and networking hardware, as well as the virtualization or hypervisor layer.

The IaaS provider also supplies a range of services including detailed billing, monitoring, log access, security, load balancing and clustering, as well as storage resiliency, such as backup, replication and recovery.

In Fig 11, the configuration supports the bus or pipeline architecture where each submodule could be added as it is developed and data exchange between modules is seamlessly addressed.

The Mobile Framework for Farming as a Business via Benchmarking Crop Prototype Business modules

All five components of the FAABB business model were implemented in a customized way. Figure 13 provides a snapshot of the main screen that shows the modules. Domain knowledge recognition was largely driven by ontologies for rice adopted from Food and Agriculture Organization of the United Nations (FAO) nomenclature. The farm characterization was driven by software companies experience in implementing similar projects for the Government of Tanzania.
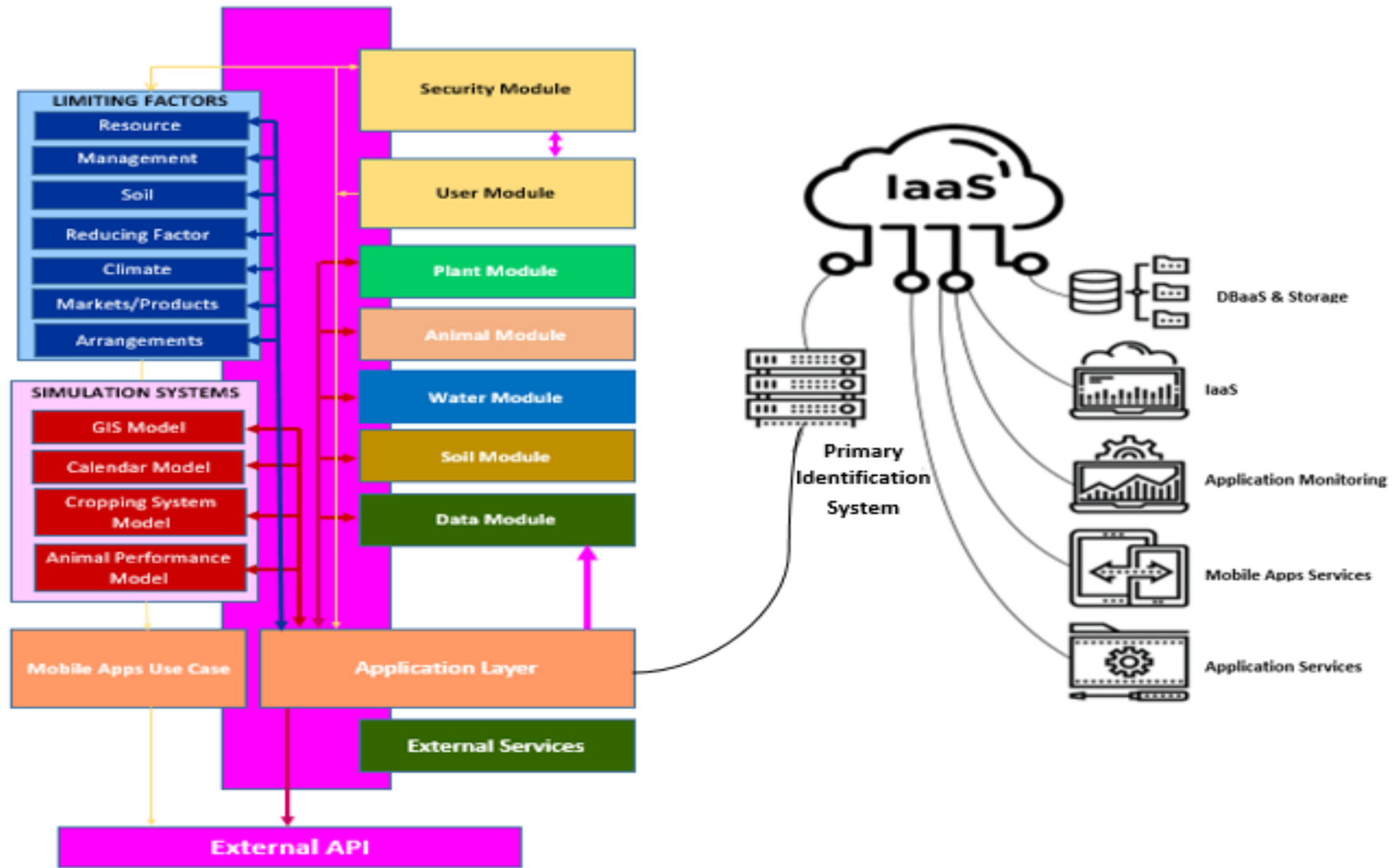
Figure 12: The NoSQL-based System Architecture for Case Study 1 Based on Software-as-a-Service
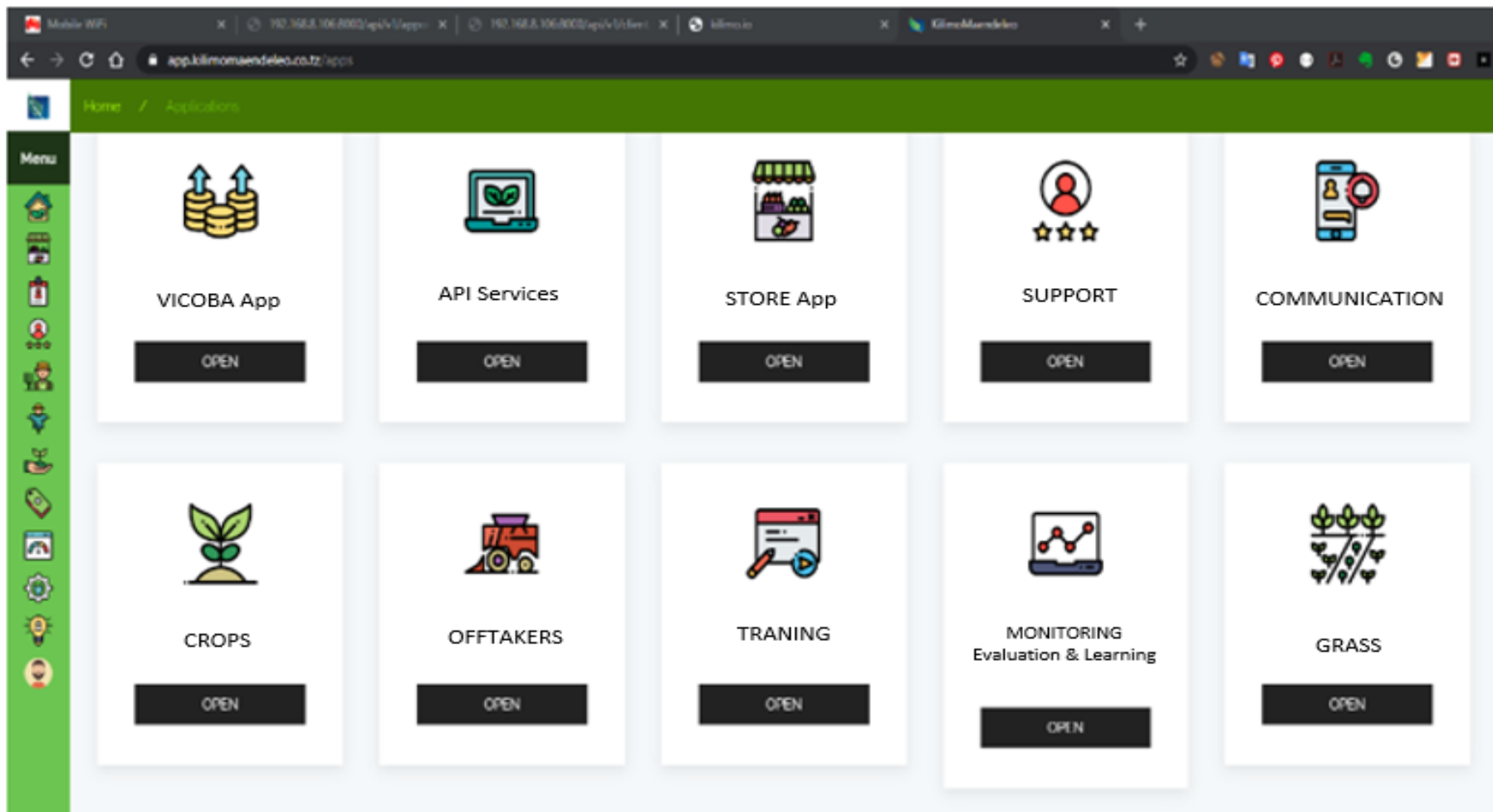
Figure 13: System Modules Implemented for Mobile Framework for Farming as a Business via Benchmarking Case Study I

(ii)   Case Study 2: The Dairy Production Use Case

The second case study was an instantiation of the m-FFAABB based on the dairy production business logic and use case scenarios. The Dairy ontology and "How-To" guides have been adapted from a New Zealand context to support the dairy producer context in prototype and were made available on line in the database context. Over time these guides will be updated for the Tanzanian context. The business model for the m-FFAABB dairy prototype is shown on Fig. 14.

The System Setup and Development Infrastructure

Figure 15 presents the architecture that was adopted by the second company that was selected by SAGCOT to pioneer the realization of the m-FFAABB in the livestock subsector. The company embraces the licensed software development based on Oracle database platforms. The system was developed and deployed based on java technologies. It is a platform independent application which supports all those operating systems which support JAVA. The system user interfaces are accessible through data network like Fiber, Digital Subscriber Line (DSL), Worldwide Interoperability for Microwave Access (Wi-Max), General Packet Radio Service (GPRS), the third generation of wireless mobile telecommunications technology (3G) etc. Data collection is performed through web interface and android based mobile applications, which can be installed in any android based device. The server should have public Internet Protocol (IP) address or Virtual Private Network (VPN) connectivity to access the application through a Web Interface. For testing and security reasons, access was set up through a VPN connectivity instead of Public IP Address.

The software has eight core modules: Farm Master Data, Livestock, Benchmarking/Farm Key Performance Indicators (KPI's), Soil Benchmarking, Plant Benchmarking, Herd Performance, Operating Toolkit, and Farm Technical Support. The Operating Toolkit has three sub modules for each of Soil, Pastures and Animals that include a series of How-To guide that describe how processes are conducted on farm.
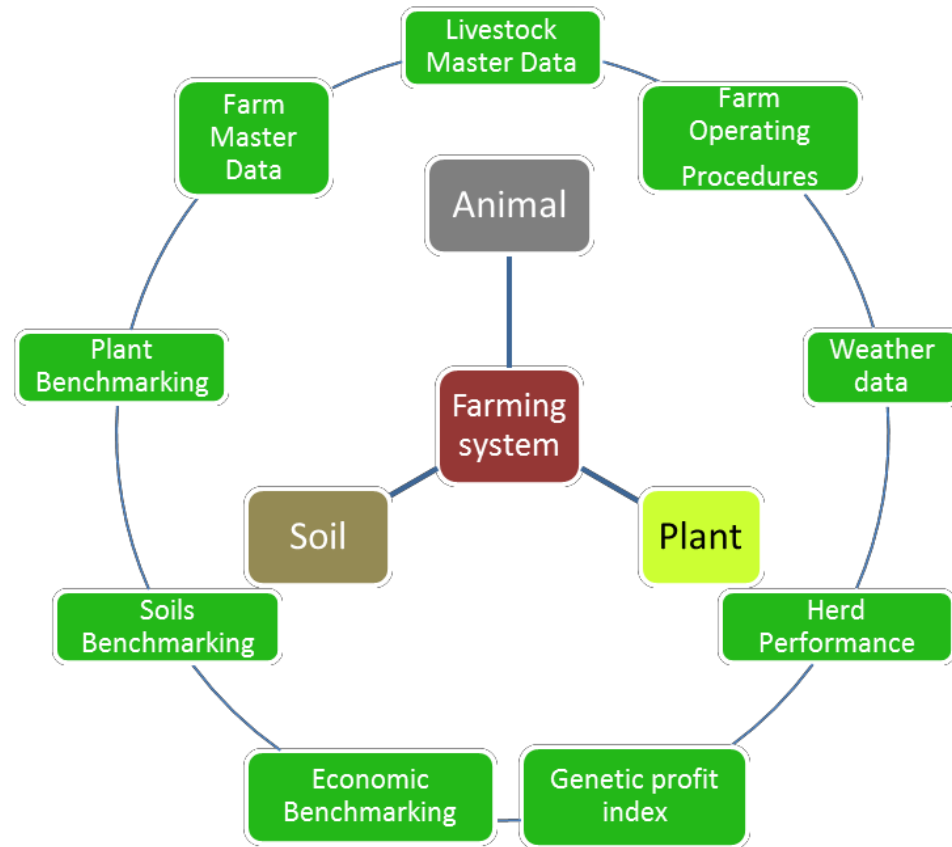
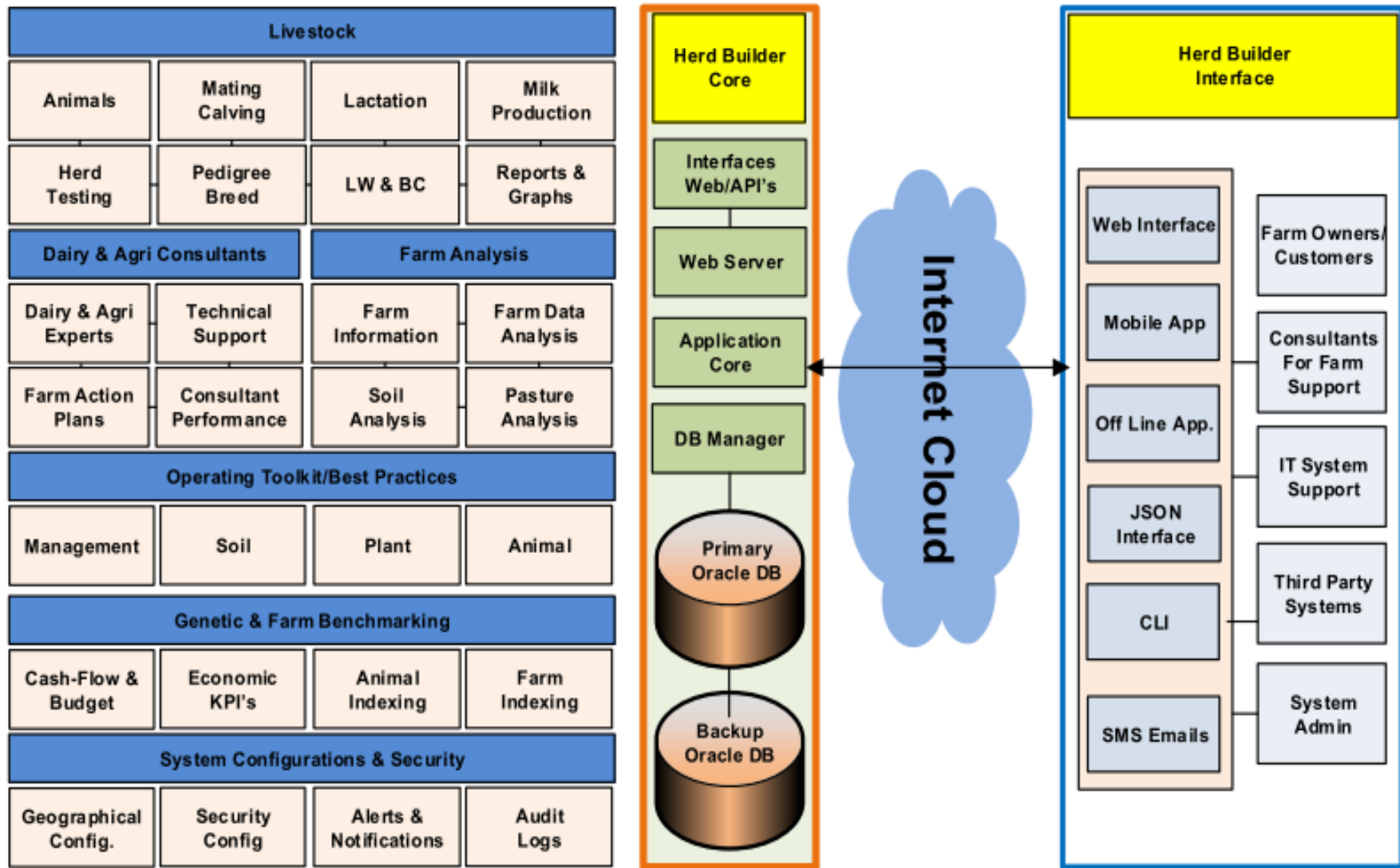**Figure 14: The Dairy Prototype Business Model**

Figure 15: Oracle-based System Architecture for Case Study 2

The Mobile Framework for Farming as a Business via Benchmarking Dairy Prototype Business Modules

- **Farm Master Data Module**

Farm master data module is the key baseline data for all the modules of the m-FFAABB package, and all the inputs shall be as accurate as possible. The users are able to be restricted by any validation table, currently the records are separated by Facilitator.

Once records are created relating to the Farm Master Data module, records are linked to other modules. The Farm Master Data can be amended, but it cannot be deleted without deleting all the related records first. The Farm Master Data is presented in a way where the farm entity has to be set for first time and then the system will allow the user to navigate across the functionality of each entity, and then add data to a particular farm in each module.

- **Soil Assessment and Benchmarking Module**

Soil assessments module has been developed with the aim to help evaluate the overall health and status of the soil on farm. Conditions of the soil are important determinants of the productive performance and quality of the pastures, and have deep effects on profits. Farm managers need consistent, quick and easy to use tools to help them assess the condition of the soil for forage production, and make informed decisions that will lead to profitable use of the land under good environmental management.

The scope of this module is to collect information of the soil status of the farms for enhancing the dairy farming production system. The data gathered identifies the soil characteristics of farms based on visual assessment done by the EO, and chemical analysis done by specialized laboratory if the farmer can afford the associated costs.

This module has two categories, Visual Soil Assessment (VSA), as shown on Fig.16 and Chemical Soil Analysis (CSA), as shown on Fig. 17. The VSA will provide an immediate effective diagnostic tool to assess soil quality, with results easy to interpret and understand. CSA on forage soils includes pH, Phosphorus, Calcium, Potassium, Magnesium, Sulphur and other elements relevant for the country. There may be abnormal levels of some nutrients due to previous management practices and/or fertilizer programs. Guessing work about nutrient management is avoided and allows cost effective fertilizer program implementation.

Figure 16: Visual Soil Assessment

Figure 17: Chemical Soil Analysis

- **Pasture Assessment and Benchmarking**

Pasture assessment module has the aim to help evaluate the overall health and production of the pasture. Pasture quality has profound effects on long term profits, farmers need reliable, quick and easy to use tools to help them assess the condition of their pasture grazing, and make informed decisions that will lead to profitable farming and environmental management.

The scope of this module is to collect information of the pasture status of farms. The data gathered identifies the pasture characteristics of farms, using a non-quantifying assessment, and chemical analysis done by specialized laboratory if the farmer can afford the associated costs.

This module has two categories, Visual Pasture Assessment (VPA) as shown on Fig. 18 and Chemical Pasture Analysis (CPA) as shown on Fig. 19. The VPA will provide an immediate effective diagnostic tool to assess pasture quality, and the results are easy to interpret and understand. The CPA should be done to measure Dry Matter (DM), Metabolisable Energy (ME), Crude Protein (CP), Neutral Detergent Fibre (NDF) and other relevant elements for the country.

- **Livestock Event Management**

The scope of the livestock master data module helps the EO to pre-emptively assist and plan interventions at the individual animal level. As shown on Fig. 20, the system has extensive capabilities to record data for each individual animal and provide reports to proactively manage the livestock. The module records main events such as production, reproduction, lactation, health treatment, weight and ancestry.

Figure 18: Visual Pasture Assessment

Figure 19: Chemical Pasture Assessment (CPA)

Figure 20: Event manager for the Livestock

(iii)   Integration Framework Between the two Prototypes

It is necessary that the system architecture embraces the separation of concerns in terms of system long term investments by various developers. The operational system that captures farm level data and produces basic report (which is the developer's main concerns) is explicitly separated from the data warehouse system (which is the primary investment by CREATES at NM-AIST). The type of technology, standards and interfaces and tools used to generate reports at the operational database levels and at the data warehousing levels is an ongoing activity within the value chain management practices at NM-AIST.

Framework for Integration for External Benchmarking at Nelson Mandela African Institution of Science and Technology

Figure 21 provides a framework for integrating data between the two systems. However, internal configurations and benchmarking models were kept specific to each developer. In addition, it was necessary that once the reports are validated then they are kept at NM-AIST server for continuing investigation of meta-level benchmarks and crosscutting issues at the NM-AIST lab. In turn, this would facilitate external benchmarking for new mobile apps developed based on m-FFAABB. The API developed for external benchmarking is provided in Appendix1.
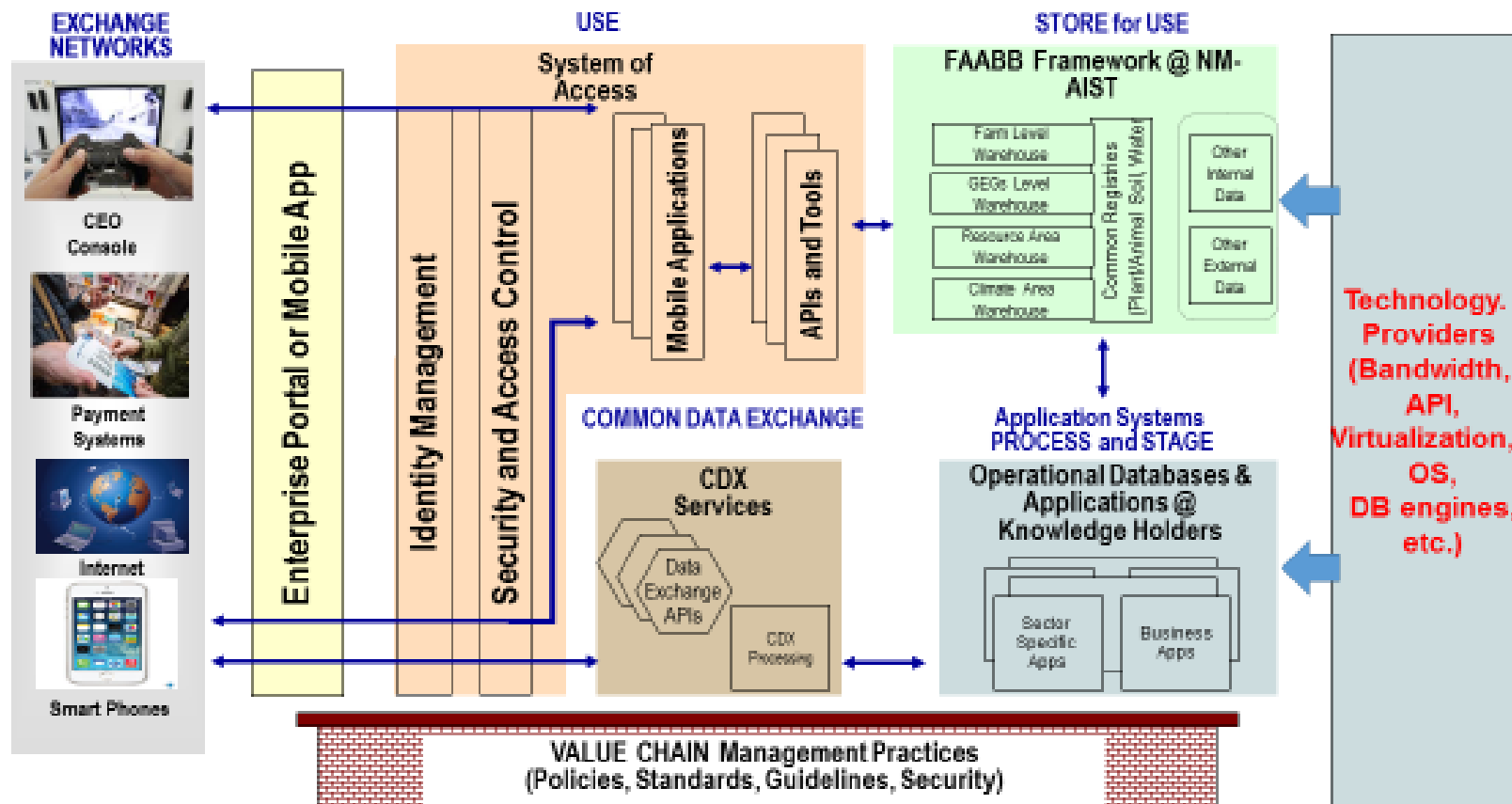
Figure 21: A framework for Data Integration Between the two Systems

External Benchmarking Services at NM-AIST through RESTful Application Programing Interface

The framework was configured to have two levels of APIs. First individual m-app system developers were allowed to develop their own APIs that could be used for internal benchmarking independent of NM-AIST. In Figure 21, this is shown as a CDX Service comprising of data exchange API and Internal benchmarking processing. It was only necessary to use NM-AIST APIs for the purposes of external benchmarking.

Consequently, NM-AIST m-FFAABB system was configured to have two interfaces. The first interface was a direct connection between NM-AIST (as a data warehouse) and the two prototypes. This allowed a direct dump of all critical benchmarking reports that were produced by individual systems. In this way, NM-AIST was regarded as a back-up system for the two systems. The second interface was a RESTful API developed to standardize the external benchmarking for each of the two systems but also for the new ones that could be developed by other m-app developers. In Figure 21, this is labeled "APIs and Tools". A detailed RESTful API for external benchmarking is documented as Appendix I.

4.1.4 Summary of Results

Up to this stage, this chapter has presented the m-FFAABB as a framework that includes twelve components to support EOs in their activities. These components are proposed through examining the relevant literature and are classified based on type of their functionality, which are either facilitating or unifying components. Facilitating components target individual stages of the farming decision process. These include the value-chain ontologies and product defining factors components for the domain recognition stage; the GEG generator, farm characterization, and event manager components for the farm characterization stage; the production manager component for the farm management stage; the constraint manager component for the limiting factors control stage; and the resource utilization, farm productivity and farm profitability components for the post-production evaluation stage. Unifying components are responsible for integration and coordination among the facilitating components, which are the FAABB data collector and FAABB knowledge codifier components. Each component is proposed based on the corresponding identified studies in the literature as well as expert opinions, as listed in Table 4 due to the modular approach used, the design of the framework allows incorporation of existing work from the literature into the proposed framework, as well as extensions of the framework by adding new components.

The chapter also presents external benchmarking services to be hosted at NM-AIST through CREATES to reinforce the m-FFAABB framework. As supplemented with the knowledge codification approach, the m-FFAABB framework embraces the collect, analyze, share and actuate phases of a typical knowledge codification system. The knowledge codification approach brings new functionalities to each component of the m-FFAABB framework as summarized in Table 5. Also proposed in this chapter are automated data collection methods, which are mobile based and IoT based methods, to provide data for the framework. In addition, the preferred data exchange method through m-FFAABB API has been presented in this chapter.

This chapter also has presented the realization of the m-FFAABB through two prototypes. The first prototype was developed based on open source NoSQL database and applied to model FAABB for rice farming. The second prototype was developed based on Oracle database and applied to model FAABB for dairy farming. Both systems demonstrated to have the basic features of m-FFAABB across all five stages of business logic as well as the unifying components. Both systems provided their own APIs for facilitating internal benchmarking and used the NM-AIST APIs for facilitating external benchmarking. The RESTful API for external benchmarking was developed, tested and validated. It is presented in Appendix 1.

4.2 Discussion

4.2.1 Discussion on Functional Evaluation

The definition used in this study to describe and understand the scope, the desired outcome of the testing and validation process is the one below, differentiating between the objectives from two points of view:

(i)   *Validation*: "Are we building the right product?" e.g. Is the software usable for the end users?

(ii)   *Verification*: "Are we building the product right?" e.g. Are there defects or bugs in the code?

As for the difference between "validation" and "verification", it is important to note that verification is a related, yet very different concept and requires specific procedures to be applied properly. Verification essentially means to ensure that the software has no serious defects or flaws, such as software bugs. It should be noted that tracking and resolving defects is not in the scope of the particular evaluation discussed in this section. As mentioned above,

the user validation tests are used to look at the modules from a functional perspective. The assumption here is that multiple m-app developers will instantiate their prototypes and before they are released, they will be subjected to the conformance tests to the framework standard user interfaces. Consequently, the candidates' main contribution (as a software engineer) was designing the entire system (Sections 4.1), specification of JSON interfaces (Appendix 1) and design of test kit (via SUS questionnaire) for data models and analysis of their acceptance to agronomical practices prescribed in the m-FFAABB business logic.

(i)   Method

As described in Kahan (2010) and extensively discussed e.g., in several websites (Qiang *et al.*, 2011), user/stakeholder stories differ from use cases. While user stories describe desired functionality of a system in natural language, use cases often follow a formal structure (template) and cover details such as preconditions, steps in a success scenario, or processed data. However, the relationship between stakeholder stories and use cases is not simply a generic matter of detail but highly depends on the scope of a stakeholder story. In some cases, a single stakeholder story might be transferred to a whole use case specification. Therefore, a practical method of testing the system functionality from the user point of view is to document use cases as stories.

(ii)   Task Design

The use case descriptions were derived from the stakeholder stories collected at various stakeholders' workshops. Six use cases were generated for testing the system functionality. For each of the test cases typical approach involved the following four steps: (a) Identify stakeholder stories that cover functional requirements on the system, (b) Group the stakeholder stories and identify related user stories and the nature of the relationship such as generalization and specialization, (c) Identify user stories that can be transferred to whole use cases and those that correspond to parts of use cases, and (d) use the story tellers as testers for the completeness and correctness of the use cases.

(iii)   Experimental Setup (Use cases)

Test Use-Case 1: Benchmarking for Farm Selection

It is important to identify farmers in the learning group or in the area who are performing well and can be regarded as benchmarks. With technical guidance from the extension worker, farmers should agree on the farm or farms to be selected. It is also important that those are

considered representative of a known farm type, so that those conclusions drawn from benchmarking will have the widest possible application. A critical outcome of this process is to document and prescribe the basic farm data elements and their average values.

Test Use-Case 2: Benchmarking for Grassroots Economic Groups Performance

Comparisons of the performance of the smallholder farmer's business with the benchmark farm are made at group-farm level as opposed to individual farmers. Sales and food security indicators were used to analyze performance of GEGs in SAGCOT and identify gaps. These gaps can suggest weaknesses within the farming system and the reasons for them. Once areas of improvement have been identified, it is useful to compare them with benchmark farms in more detail. Digging beneath the data will help to understand why a particular farmer in the GEG is not doing better than the farmers in the benchmark group.

Test Use-Case 3: Benchmarking for Change Management

The purpose of identifying performance gaps and their causes is ultimately to introduce actions and devise plans that the farmers in the GEG can use to improve the performance of their farms. Plans should include realistic targets for each farmer to achieve. An EO can encourage, and support farmers and guide them in action planning through automated case studies retrieved through a smart phone. The interest was to find out how many members of the GEG contributed to half of the GEGs total production and half of its sales.

Test Use-Case 4: Benchmarking for pH Content

 The soil pH is a measure of the acidity or alkalinity of the sample. It is important in the way it influences the chemical and physiological processes in the soil, and the availability of plant nutrients.

Test Use-Case 5: Benchmarking for Economic Indicators per Monitor Farm

The analysis of farm economic indicators data derived from actuals in the economic benchmarking module database over the period selected, will enable the user to review the main factors contributing to Economic Farm Surplus (EFS) of a farm. Likewise, the user will be able to analyze the data under three main categories which are results per farm, hectare and per litter.

Test Use-Case 6: Benchmarking for Animal Distribution

At a ministerial level, it is necessary to analyze the distribution of animals in different categories region-wise. This may provide some clue in terms of where facilitative resources and interventions should be concentrated. Comparing the concentration of different animals in different ecological zones may be a useful report from the system.

4.2.2 Discussion of the Results from Crop Production Prototype System

This section presents snapshots of the reports for the first three use cases. The reports were consistently configured to present data in four different formats. On top of each report is a summary of information from the population within the parameters that were chosen for the analysis. At the bottom left the report presents a map of Tanzania indicating the location(s) that are associated with the population under investigation. The semi-circled graph on the left presents the selected parameter values relative to the population values. The detailed benchmarking analysis is presented in three different views: The tabular view on the upper right corner, the bar chart in the middle of the report, and pie charts at the bottom left corner. In this way it becomes easy for various stakeholders to interpret the FAABB results consistently.

(i)   Results for Use-Case 1

Figure 22 presents a sample of the report of potential maize farmers in Tanzania. As indicated in the report, the map shows data from villages in the entire country where farmers are involved in growing maize. In the map, the size of the circle is proportional to the number of farmers who grow maize. Villages with small grey dots have potential for growing maize, but are currently not registered in the system. Both the table at the top right corner and the bar chart at the bottom left corner indicates the best seven regions with high number of maize farmers. These regions exceeded the benchmark of having at least 20 000 farmers involved in maize business. From this report, it was easy for the banks and donors to invest in the four regions of SAGCOT that passed the benchmarks (i.e. Morogoro, Pwani, Ruvuma, and Iringa regions). Each of the views displayed on the screen could be amplified by clicking on the view under consideration.

(ii)   Results for Use-Case 2

In Fig. 23, the red circle on the map indicates the location of Songea rural as the focus of analysis. As indicated in the report, the acreage covered in maize is only 11 620 compared to

the total available acreage of 34 767 acres in the Songea rural district. The report further indicates that only seven villages contribute to the high number of sales and have the highest reserves that contribute to food security. This report could trigger more analysis to find out why these villages were performing better than the rest of the villages, which are seemingly subjected to the same climate.

(iii)   Results for Use-Case 3

In Fig. 24, the population covers only one GEG. The report shows that only 9 out of 25 members of the GEG contributed to half of the GEG's total production and half of its sales. The analysis shows further that the same nine members contributed almost 70% of the food security requirements for the GEG. This benchmarking report provides the basic insights for addressing the problem of what is wrong with the rest of the members in the same GEG. In this way, the EO was able to use the system reports in guiding discussions with farmers in the GEG. As noted here, in the absence of benchmarking analysis, it was difficult to convince the farmers to change. Most of the farmers in rural areas rely mostly on their traditional belief. Unless one comes with such evidence-based analysis, it is difficult to manage change.
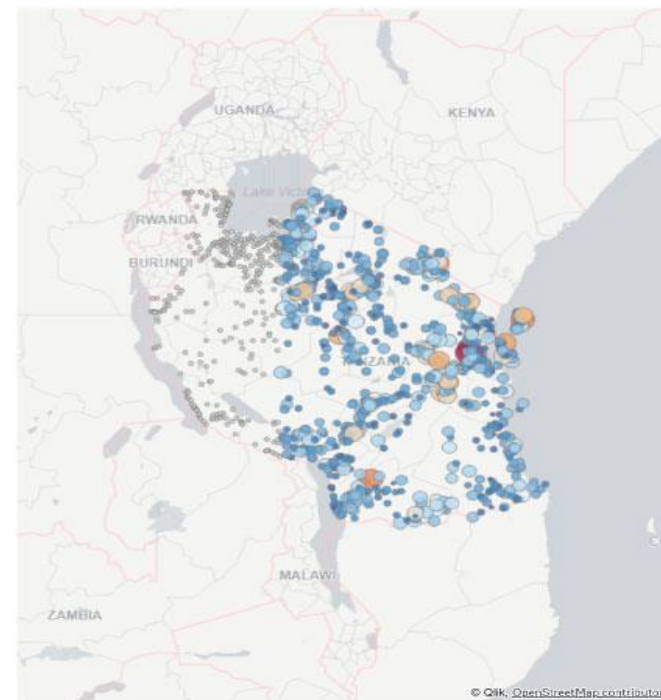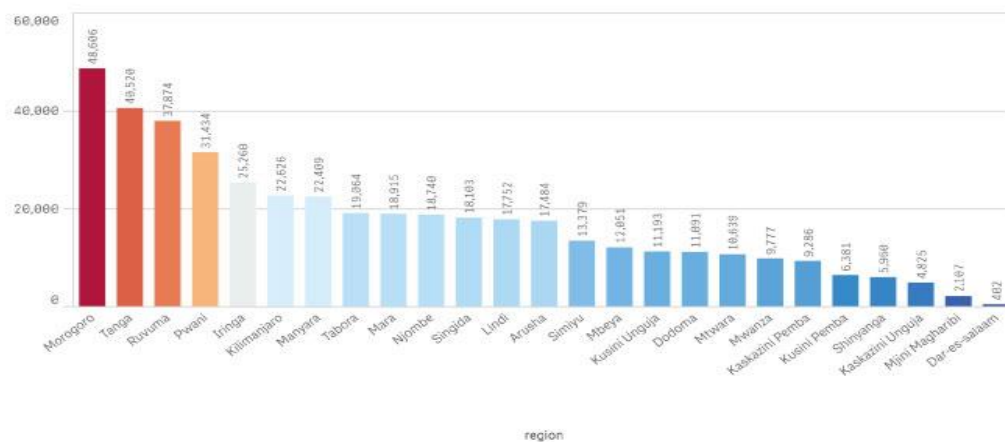
Figure 22: Farming as a Business via Benchmarking Report for Selecting the Benchmark Maize Farms
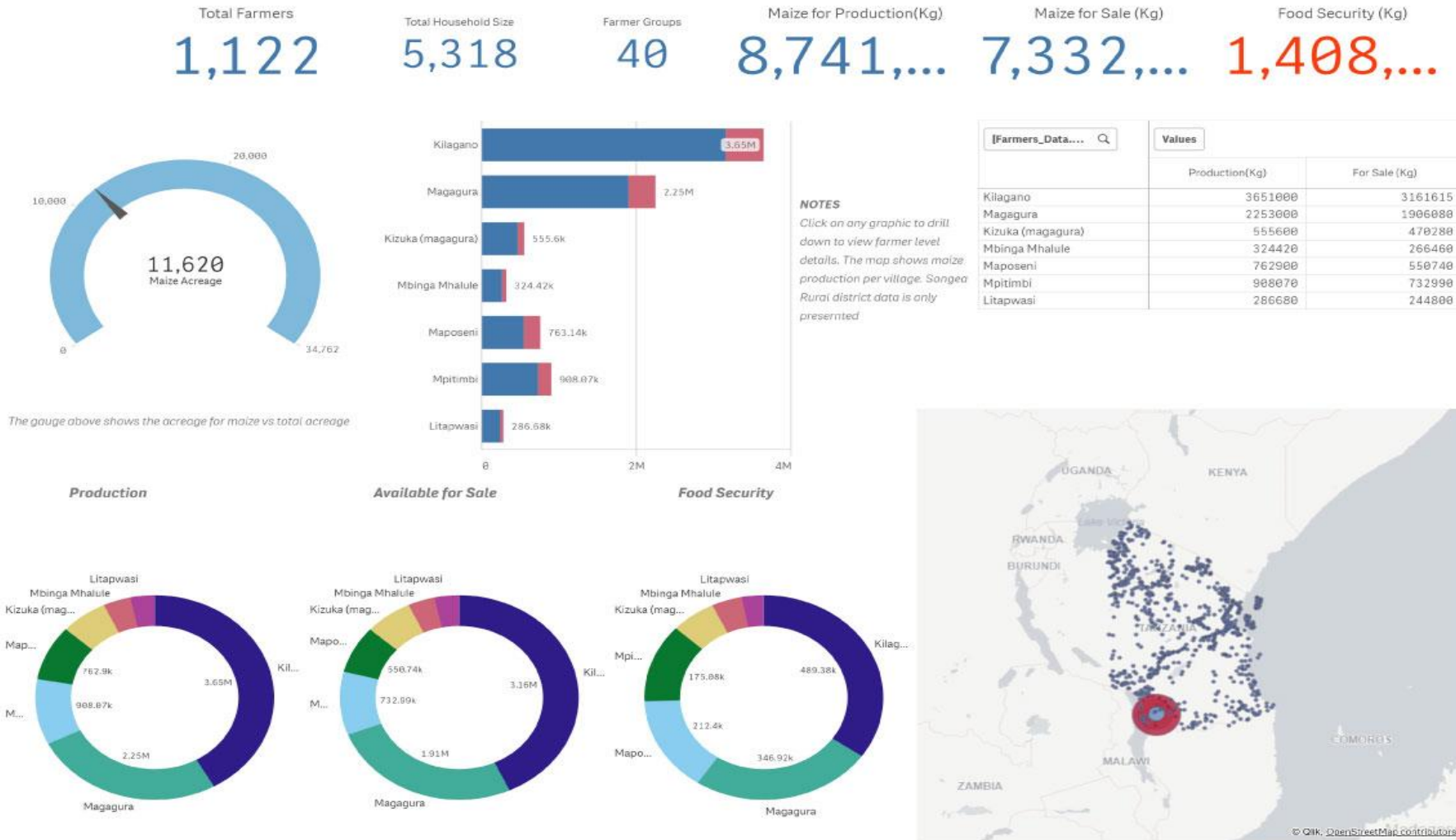
Figure 23: Farming as a Business via Benchmarking Report for the Performance of Grassroots Economic Group's in Maize Production
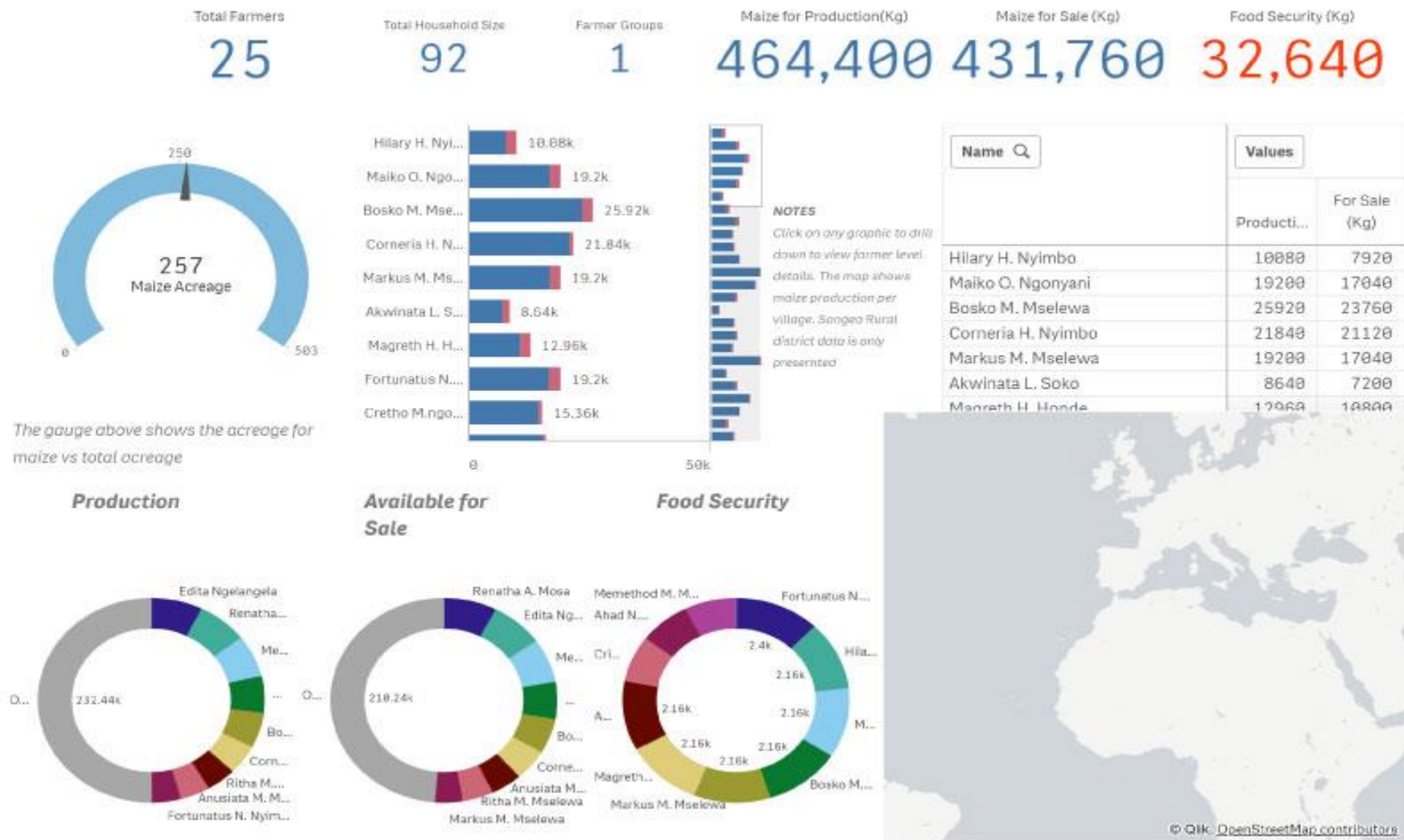
Figure 24: Farming as a Business via Benchmarking Report for Managing Change within Grassroots Economic Group Member Farms

4.2.3 Discussion of the Results from Livestock Production Prototype System

The core purpose of the prototype was to record and benchmark farm economic performance of dairy herds of all sizes, in order to identify the top 25% of the industry within each management system, and to drill into why they are outperforming their peers, confirming critical best practices. The performance data analysis identifies the elite animals in the upper quartile to assist farmers with selection decisions (breed and strain) and to develop and refine a local profitability index for cows, cow families and the future local bull team.

(i)   Benchmarking for pH Content

The soil pH is a measure of the acidity or alkalinity of the sample. It is important in the way it influences the chemical and physiological processes in the soil, and the availability of plant nutrients.

Provides a snapshot benchmarking report on the effect of pH ($CaCl_2$) on the availability of soil nutrients. The report shows high concentration of iron, manganese, boron, copper, zinc and aluminum. The report also shows moderate availability of nitrogen, phosphorous, potassium, Sulphur, calcium and magnesium. Molybdenum is shown in the report as being less available. On the overall, the effect of pH on the availability of nutrients make the soil relatively acidic. Consequently, the farmers may be encouraged to undertake liming to reduce the soil acidity.

(ii)   Benchmarking for Economic Indicators per Monitor Farm

The analysis of farm economic indicators data derived from actuals in the economic benchmarking module database over the period selected, will enable the user to review the main factors contributing to EFS of a farm. Economic Farm Surplus per hector (EFS/ha) is the key measure used in this technological platform to compare performance between farms during a chosen period, and so, determine the level of progress or contraction of the business unit at a given time during a period through an analysis of the data available. The EFS is a function of the quantity of items sold per hectare multiplied by the per unit EFS of each item sold. This operation is useful for quickly diagnosis how a business is performing compared to others, and the areas that may require improvements.

Figure 26 presents a typical report for analysis of the annual economic benchmarking report under three main categories which are results per farm, hectare and per litter. It shows a

typical farm of 9.71 hectares producing a total of 18,080 litters, which is an average 1861 liters per hectare. At an average investment of US$ 8136, a daily farm explicit expenses of 4132 and economic farm surplus (EFS) of US$ 4003.17 and economic contribution ration of 49.20%. The analysis indicates that the dairy business in the year under consideration was profitable.

(iii)   Benchmarking for Animal Distribution

The system has a "Get Report" tool that is used to view number of animals in different categories. A click on "All Animals" button retrieves a list of all registered animals with additional information such as; Visual Tag, Breed, Gender, State, Milking Status, Mating Date, Lactation Start date, Expected Calving Date, Dam and Sire Information.

As shown on Fig. 27, a snapshot of a typical report for the farm shows that the   farm with named DSL001 has a total of 59 animals out of which 13 are of type "Calf", 4 "Heifer, 35 "cows", and 7 "Bulls".   As a consequence, a distribution graph provides respective percentages that guide the discussions between EO and farmers in a GEG. A typical influence of such a benchmarking report may be resource allocation, of even control measures in terms of reduction of some species to maximize the market requirements. The report shows that the cows take a bigger share of the investment (59.32%) followed by calf (22.03%)

.

FIGURE 3.
Effect of pH (CaCl₂) on the availability of soil nutrients
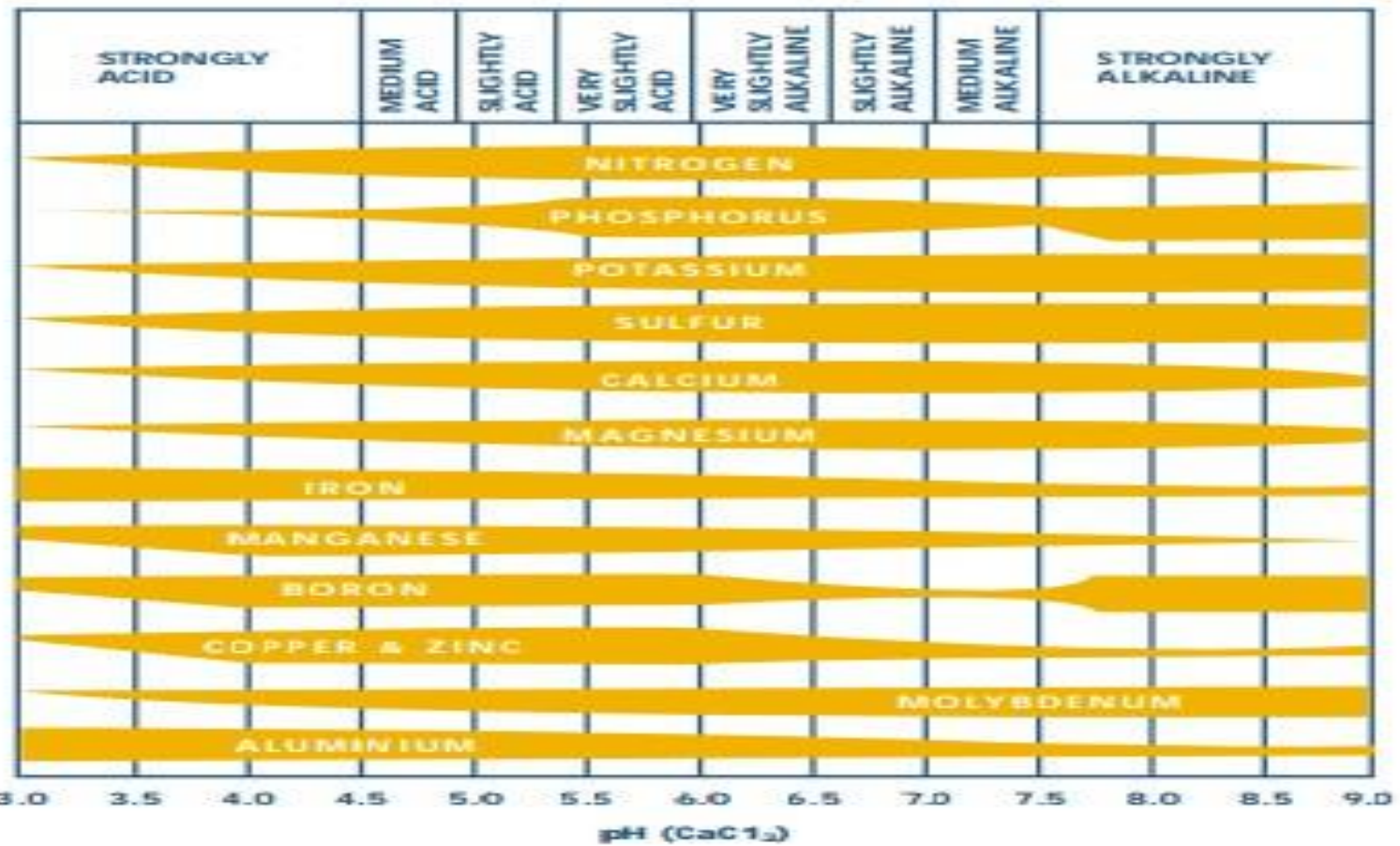
Figure 25: Benchmarking for Soil pH Content

Farm Name   Asociacion Jabari Guagra
Consultant   Paul Gibson
Address   San Francisco Turucuchu
Province   PICHINCHA
Parroquia   AYORA
Supply Company   El Ordeño
Altitude   3100.0

Farm Code   MF076
Farm Size(Hectares)   9.0
Location Phone #   0986967034
Canton   CAYAMBE
Farm System   Specialized Milk
Supply Number
Lat / Long   0.084616 / -78.031809

From Month/Year   May   ▼   2015   ▼   To Month/Year   May   ▼   2016   ▼   **Generate Report**

Economic Report from May 2015 to May 2016			
✱ ◆	Parameter ◆	◆	◆
1.	Total liters of milk sales	18080.0	
2.	Effective daily farm hectares	9.71	
3.	Total liters per hectares	1,861.18	
4.	Average cows milked in this period	12.00	Liters/Cow	1,506.67
5.	Average price per liters	0.45	
		Total $	$ /ha	$/ Liters of Milk
6.	Total Milk sales	8136.0	837.53	0.45
7.	Cattle Sales	0.0	0.00	0.00
8.	OTHER (dairy farming sales	0.0	0.00	0.00
9.	Gross Dairy farm revenue (Cash income)	8,136.0	837.53	0.45
	Dairy farm explicit Expenses (Cash Out)	Total $	$ /ha	$ /Liters of Milk
10.	Labour and Management	2,209.28	227.43	0.12
11.	Animal Health and Mating	486.95	50.13	0.03
12.	Soil	284.00	29.24	0.02
13.	Grazing	485.00	49.93	0.03
14.	Feed	239.90	24.70	0.01
15.	Farm running and maintenance	196.01	20.18	0.01
16.	Administration	0.0	0.00	0.00
17.	Overheads	231.69	23.85	0.01
18.	Dairy Farm explicit Expenses (Cash Out)	4,132.83	425.44	0.23
19.	Cash farm surplus (CFS)	4,003.17	412.09	0.22
	Implicit Adjustments		$ /ha	$/ Liters of Milk
20.	Labour Implicit Adjustment	0.00	0.00	0.00
21.	Subsidy implicit adjustments	0.00	0.00	0.00
22.	Owned support block implicit adjustment	0.00	0.00	0.00
23.	Dairy farm implicit adjustment	0.00	0.00	0.00
			$ /ha	$/ Liters of Milk
24.	Dairy farm economic expenses (EcEX)	4,132.83	425.44	0.23
			EFS/ha	EFS/liters
25.	Economic farm surplus (EFS)	4,003.17	412.09	0.22
26.	Economic Contribution Ratio %	49.20	49.20	49.20

Figure 26: Benchmarking for Economic Surplus Indicator

All Animals   **New Animal**

Farm Code [DSL001]   Farm Name [Dairy and Beef SolutioNZ]

Report Options State Wise ▼   **Get Report**

Animals

#	State Desc	No Of Animals	%
	Registered Animals		
1	Calf	13	22.03 %
2	Heifer	4	6.78 %
3	Cow	35	59.32 %
4	Bull	7	11.86 %
	Total	59	

Un-Registered Calved	
Calves	3

Cow (59.32%)
Heifer (6.78%)
Bull (11.86%)
Calf (22.03%)

Figure 27: Benchmarking for Animal Distribution

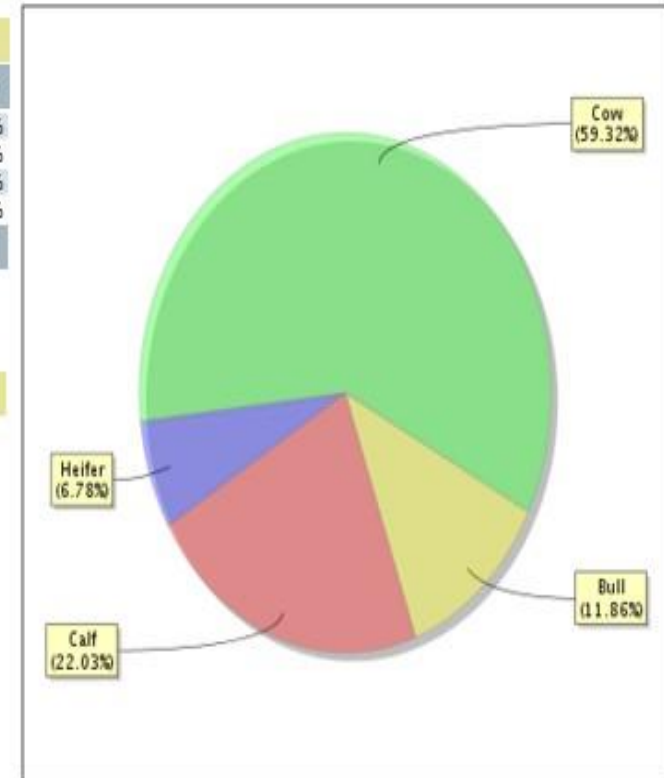Functional requirements validation was covered mostly for selected use cases of the m-FFAABB prototyping. Still, as the prototypes continue to evolve, more functionality will be added. However, most of the modules available by these prototypes were tested both in the field with EOs as well as through round table discussions with experts.

4.2.4   Discussion on Usability Evaluation

In this research, a usability test was designed to evaluate the effect of the developed m-FFAABB prototype on user performance and user experience, as well as to assess if it is effective, efficient and satisfactory, and if it has any superiority over conventional methods used in the FAAB decision process. The m-FFAABB consists of a wide range of features. Accordingly, this usability study does not cover all features of the components of m-FFAABB; it focuses on decision support functionalities of the prototype. A mixed data collection method combining quantitative performance measures (the task completion time and error rate) with qualitative measures (the usability questionnaire) was used.

(i)   Method

International Organization for Standardization (ISO) defines the usability of a product as the extent to which the product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use (Bevan & Carter, 2016). System Usability Scale (SUS) was selected   as the usability questionnaire for the qualitative usability evaluation (Brooke, 2018). As elaborated in Section 3.3.6, the SUS consists of 10 five-point Likert scale type items that are alternating five positive statements and five negative statements to have respondents read each statement and make an effort to think whether they agree or disagree with it (Brooke, 2018).

(ii)   Task Design

Six tasks were determined for experiments as shown on Table 6. First, EOs were asked to complete these tasks with conventional methods. Then, they were asked to complete the same tasks with the prototype application. The first case is named "the manual case", and the second "the prototype case". The products were differentiated for these two cases to prevent learning effects.

For the manual case, the participants recorded their findings in a given form. Error rates were measured using the data in these forms. The time for completing all task, and the number of necessary benchmarking reports produced were recorded. For the prototype case,

mobile phones that run Android OS and the developed prototype application were used. The EO interactions with the prototype, and timestamps of these interactions were logged.

Table 8: Defined Tasks for Experiment

Task	Task Description
Task 1	Identify your product and convince your farmers on why they should engage in such farming by citing potential markets and their output requirements.
Task 2	Identify registered farmers in their groups and ascertain their farm ownerships and prepare the investment plan necessary for achieving the required production levels (including the required farm inputs).
Task 3	Identify critical production events and assign each event to a known farm-employee / input-supplier / service-provider.
Task 4	Establish statistics on the existing levels of soil acidity, water contents, and herb type and compare them to known standards for a particular production as a basis for identifying additional farm inputs.
Task 5	Identify all potential constraints and engage service providers for their mitigation; and communicate the mitigation measures to farmers
Task 6	Gather the necessary information from the off takers on the levels attained after production and engage a service provider to compute their profitability levels and communicate the results to farmers.

(iii) Experimental Setup

Before the evaluation took place, a pilot study was conducted with three EOs, in order to refine the methodology and tasks. Two EOs found two of the tasks ambiguous, and therefore, the wording of these tasks was modified after the pilot study.

The tests were conducted in the EOs' farms for reasons of comfort. Before the tests, participating EOs were informed about the study, test procedures, tasks, questionnaire, and estimated duration. Oral as well as written instructions were provided to the participants. The participants were allowed to use a calculator to complete the tasks in the manual case. For

example, most of the participants drew a table on a sheet of paper, and used a calculator to sum up the costs to determine the profitability in Task 6.

After the test, the subjects were asked to fill out the SUS questionnaire (Brooke, 2018), and a background questionnaire that included questions to determine age, gender, computer, and mobile application usage frequency. The SUS questionnaire is a standard test commonly used to evaluate the usability of systems as explained in Section 4.2.5

According to the findings of the literature on usability evaluation, at least 20 participants were invited for the experiments. Tullis and Stetson (2004) indicate that 12 users are enough to obtain a measure of the perceived usability of a system with the SUS questionnaire. Accordingly, 20 EOs participated in the study, and there was no segregation of gender in this exercise. All participants were smartphone users. All participants indicated that they use smart phones regularly.

4.2.5 Discussion of the Results from Usability Testing

This section presents the results out of the SUS questionnaire, the comparison of the task completion times, and selection errors. A statistical significance level of 0.05 is used throughout this section. The significance level of 0.05 was chosen because the test environment was controlled to the extent that there was less chances of making too much errors but at the same time test participants were free to use their own personal judgement that their choices could be challenged by other colleagues.

(i)   Results from the System Usability Scale Questionnaire

The average SUS score for all participants was 90.52, and the standard deviation was 4.76. Figure 28 shows the distribution of the SUS scores. According to Bangor *et al*. (2009), systems which score between 85.5 and 90.9 on the SUS scale can be classified as having "excellent" usability. These scores show that the prototype has an excellent usability and "A" grade SUS score.
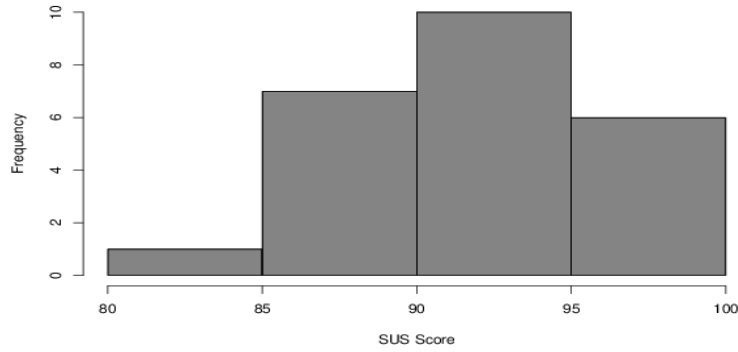
Figure 28: Histogram of the System Usability Scale Scores of the Participants

Figure 29 and 30 show specific results from the SUS questionnaires. As shown in Fig. 28, the participants gave an average rating of 4.42 or above on options related to positive statements. The participants stated that they would like to use the prototype frequently (M=4.42, SD=0.66).   They found the various functions in the prototype were well integrated (M=4.58, SD=0.51). These results imply that the integrated approach of m-FFAABB is validated. The participants also stated that they felt very confident using the system (M=4.46, SD=0.51). Moreover, they thought the system was easy to use (M=4.79, SD=0.42), and easy to learn (M=4.67, SD=0.49). As Fig. 29 shows, the participants gave an average rating of 1.58 or below on the options related to negative statements. Overall, the questionnaire results indicated that users found the features of the prototype useful, and ready to use.
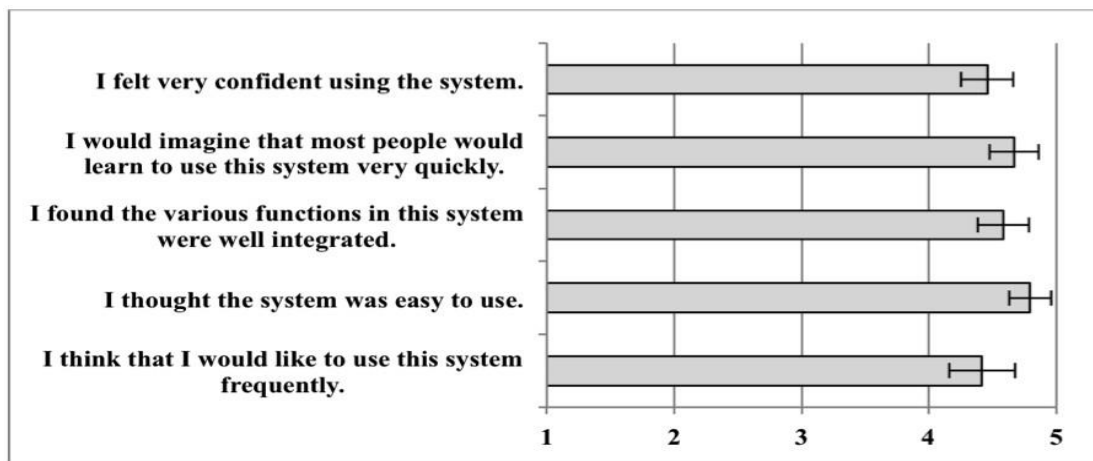
Figure 29: Result-set 1 from System Usability Scale Questionnaire (Higher Rating is Better and Error Bar   Indicate std. dev)

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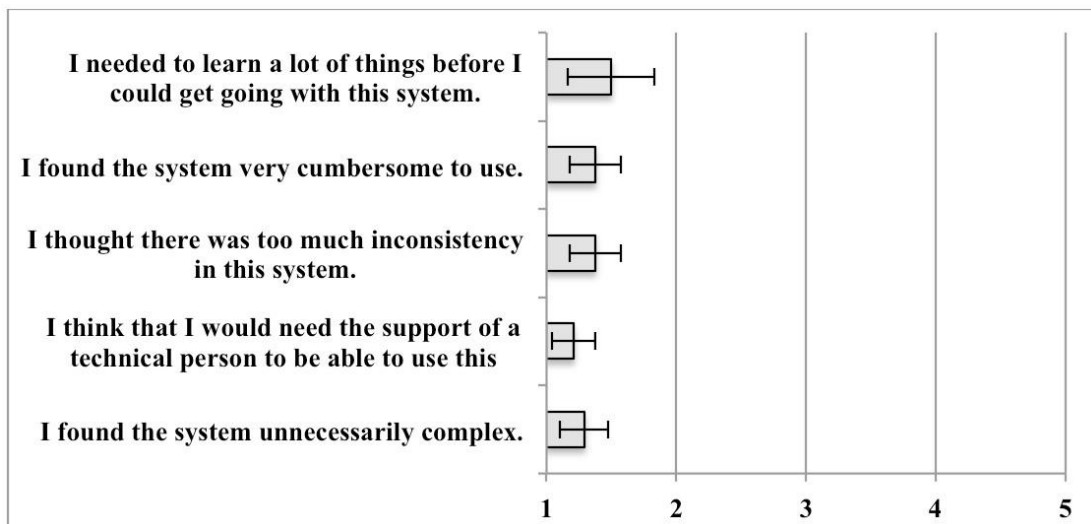
Figure 30: Result-set 2 from System Usability Scale Questionnaire (Lower Rating is Better and Error Bar Indicate std. dev.)

Comparison of Task Completion Times

Average task completion times (TCTs) for all six tasks are given in Fig. 30. A paired-samples t-test was conducted to compare TCTs in the prototype and the manual cases in Fig. 31. As shown in Table 10, there is a significant difference for all six tasks (p<0.001) in the TCTs for the prototype and manual cases. These results imply that the prototype is timesaving. Moreover, decreased TCTs imply that the prototype reduces the intellectual effort required by the farming to complete the tasks.
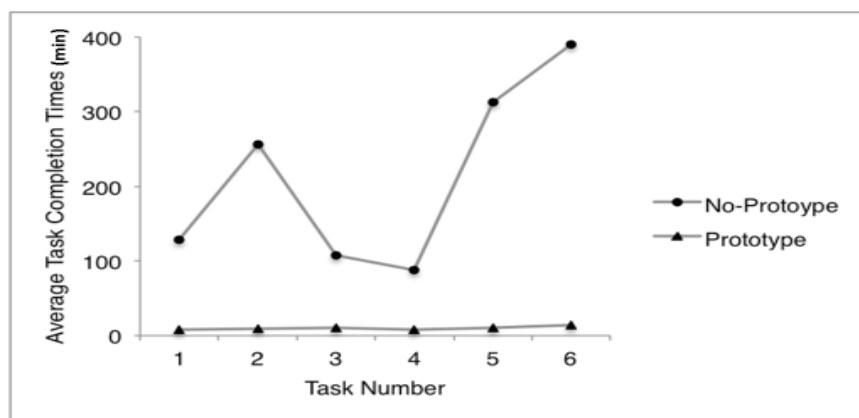
Figure 31: Average Task Completion Time (TCT) in the no-Prototype and the Prototype Cases

In addition to comparing TCTs for each task using the paired-samples t-test, a two way, repeated measures ANOVA test was also conducted to compare the main effect of the task type (the manual and the prototype) on TCTs. The test results for the ANOVA critical value "F" also indicate that the task type has a significant effect on the time spent to complete the

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tasks ($F_{(1,23)} = 678.709$, $p < 0.001$). An F-test is the measure of the likelihood that the two samples (i.e. "no prototype" Vs. "prototype") came from the two normal distributions that have different variances. As a limitation, the participants perform the tasks in the same order. They performed the manual tasks, and then the prototype tasks, in that order.

Table 9: Descriptive Statistics and t-test Results (min)

Task	No-Prototype		Prototype		N	t	df	Sig
	Mean (min)	Std. Dev (min)	Mean (min)	Std. Dev				
Task 1	128.58	41.026	7.75	3.220	24	14.289	23	< .001
Task 2	256.71	91.851	8.75	2.691	24	13.334	23	< .001
Task 3	107.92	39.989	10.21	3.257	24	12.070	23	< .001
Task 4	87.58	27.639	8.04	2.493	24	13.739	23	< .001
Task 5	313.38	92.998	10.50	1.842	24	15.996	23	< .001
Task 6	390.63	75.585	14.50	2.571	24	24.197	23	< .001

Comparison of Selection Errors

A selection error refers to a situation where a user chooses a wrong farm input provider for Tasks 1-4, or a wrong service provider, or some combination service providers for Task 5 and Task 6. The numbers of selection errors were investigated to measure the effect of the prototype on the product and store selection. As shown on Table 11, there is no selection error in the prototype case, since the prototype makes benchmarking for Tasks 1, 2, 5 and 6, and helps to filter potential alternatives for Task 3 and Task 4. For the no-prototype case, 33% of the 20 participants selected a wrong service provisions for Task 6, and 21% selected a wrong service provisions for Task 5. Of the participants, 17% selected a wrong input for Task 2, and 4% of the participants selected wrong inputs for each of Task1, Task3, and Task4.

These results show that participants could not select the minimum cost inputs and service providers in the manual case, while they selected the inputs and services providers in the prototype case; which imply that the prototype is cost saving.

Table 10: Percentage of Number of Unsuccessful Tasks Due to Selection Errors

Parameters	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6
Manual (% Errors)	4.16	16.66	4.16	4.16	20.83	33.33
Prototype (% Errors)	0	0	0	0	0	0

Overall, the results from the SUS questionnaire indicate that the developed prototypes are functional, useful, well integrated, and easy to use, which implies that the framework can be successfully used as a development tool for mobile apps that support FAABB.

Statistical comparisons of TCTs of the prototype and the manual cases reveal that there is a significant difference in the TCTs of these cases ($p<0.001$), which proves the prototype significantly decreases the time spent in the decision process, and reduces intellectual effort of EOs. Moreover, the comparison of the selection errors reveals that users make wrong decisions when selecting minimum cost farm inputs and service providers without the prototype; hence, the prototype also decreases the cost of decision making.

4.2.6 Summary of Discussions

This chapter has presented the results of prototype tests done at two levels: validation of m-FFAABB functional requirements and validation of m-FFAABB system usability through mobile apps.

The testing of the functional requirements was done through reviews of six use cases (three on each of the two prototypes). Continuing testing through expert reviews were made to improve the functionality of the framework components to accommodate variabilities of the domains and products specific implementations. Functional requirements validation was covered mostly in earlier stages of the m-FFAABB prototyping. Still, as the framework continue to evolve, functionality testing was made part of the validation process as well. The results of the tests produced readable reports in the form of figures and plots that could be interpreted by agronomists.

The usability of m-FFAABB was tested through System Usability Scale (SUS) originally developed by John Brooke in 1986 (Tullis & Stetson, 2004). Overall, the results from the SUS questionnaire indicate that the developed modules of the prototype are functional, useful, well integrated, and easy to use, which implies that the framework can be successfully used as a development tool for mobile apps that support FAABB.

Statistical comparisons of TCTs of the prototype and the manual cases reveal that there is a significant difference in the TCTs of these cases ($p < 0.001$), which proves the prototype significantly decreases the time spent in the decision process, and reduces intellectual effort of EOs. Moreover, the comparison of the selection errors reveals that users made wrong decisions when selecting minimum cost farm inputs and service providers without the prototype; hence, the prototype also decreases the cost of decision making.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5. 1   Conclusion

As presented in Chapter 1, the objectives of the reported research work were threefold: (a) To define a framework of critical value chain actors, their functions, and optimal orientation that facilitate the management of each stage of the FAABB process, (b) To develop a decision support framework, (providing basic services), that facilitates EOs to conduct guided FAABB electronically, and (c) To develop a knowledge capture and codification framework to ensure that FAABB data is available for mobile application developers for addressing a wide range of use-cases. The realization of the three objectives is confirmed in the following narrations:

(i)   The first objective was fully realized. A literature survey was undertaken on the state of system models in relation to five modelling views of the ARD systems, namely: (a) *defining factors for agricultural echo systems*, (b) *farm characterization and management practices,* (c) *simulation systems for predictable farm data*, (d) *limiting factors for agricultural optimization*, and (e) *performance estimation through benchmarkin*g. A framework of critical value chain actors and their orientation was then developed to support FAABB and tested through various use-cases in the SAGCOT. The framework of value chain actors and their orientation was then published as a journal paper (Kyaruzi *et al*., 2019b) and the same was applied to develop the information architecture for external benchmarking as part of the m-FFAABB. The m-FFAABB has three critical basic layers namely: *FAABB business support actors*, *FAABB knowledge codifier actors* and *FAABB data collector actors*. As discussed in previous sections the facilitation by value chain actors for each stage of FAABB was analysed and presented from both their compatibility as a well as benefits they bring to the internal benchmarking. The m-FFAABB setup at NM-AIST promises to address the need for cultural change among agricultural researchers to ensure that data for addressing a range of use-cases is available for future mobile application development.

(ii)   The decision support framework (through which NM-AIST can provide basic services), that facilitates EOs to conduct guided FAABB electronically via mobile apps was developed via a standardized RESTful API as a common interface for provision of external benchmarking services. The basic framework of typical API

calls was analysed, tested and results published in the second Journal paper (Kyaruzi *et al.,* 2019a); and the same was applied to influence the API for external benchmarking as part of the m-FFAABB and its detailed JSON sample data presented as Appendix 1. As discussed in previous sections the API is intended to act as a standard data access interface for all CREATES supported m-FFAABB external benchmarking services and could easily be extended as new services are made available for future mobile application development.

(iii)   The third objective (i.e. the knowledge capture and codification framework to ensure that FAABB data is available for mobile application developers for addressing a wide range of use-cases) has also been achieved. Although internal configurations and benchmarking models were kept specific to each developer, the systems were configured in such a way they could push their data and report to NM-AIST seamlessly. The framework architecture for the realization of information codification was developed and published as part of both journal papers (Kyaruzi *et al.,* 2019a Kyaruzi *et al.*, 2019b) because it formed the heart of realization of external benchmarking. Although the challenge for data exchange between NM-AIST and m-apps developers depends on policy guidelines and service level agreements between the two parties, this research work involved developers that were both sponsored by SAGCOT project and therefore made it possible to test the technical aspects of the data exchange protocols. The development of service level agreements was outside the scope of this research.

5. 2   Recommendations

Based on the success of the research work, it is hereby recommended as follows:

(i)   This research may serve as an extensible foundation for future studies on mobile information systems assisting farmers in their decision processes. As an ongoing research area, mobile technologies in support of ARD require more research efforts to gain broader adaptation of solutions on the mobile domain for addressing challenges of EOs, which are explored in the ARD domain.

(ii)   The main limitation of this research is that the developed modules of the prototype have restricted functionality compared to the corresponding proposed components in m-FFAABB. Even though the prototype does not contain all the functionalities described in the framework, the EOs that participated in the experiments stated that

they would like to use the prototype frequently. Further research may extend the framework to provide a greater degree of assistance for the farming decision process. In addition, specific algorithms designed for individual stages and integrated as modules within the framework may help further automate the process. Furthermore, future research should focus on privacy and security aspects of mobile solutions proposed to address farmers' challenges.

(iii) With regards to the required infrastructure, it was envisaged that the supercomputers at the NM-AIST would provide a base of making CREATES an external benchmarking service provider by embarking on big data projects to support FAABB. However, this did not happen due technical faults at NM-AIST High Performance Computer (HPC). Instead the m-FFAABB was implemented and proposed use-case services were simulated through cloud computing. This provides a new room for CREATES to investigate the best way to provide external benchmarking services through cloud computing.

(iv) Another area of research is the standardization and promotion of APIs for data exchange through REST with JSON data formats. This will enable mobile application developers to use the m-FAABB frequently. The API provided here is just a starting point and more are needed as the prototypes are turned into a working system.

(v) Last but not least, it should be noted that benchmarking at individual stages of FAABB as well as at unifying stages requires quite a bit of modeling. It will be interesting to have a catalog of existing and new models that could support benchmarking and these are the backbone of making CREATES a FAABB service provider. Therefore, an invitation is hereby extended to researchers from mathematical modeling and artificial intelligence (AI) to investigate on the best analytical tools for achieving external benchmarking.
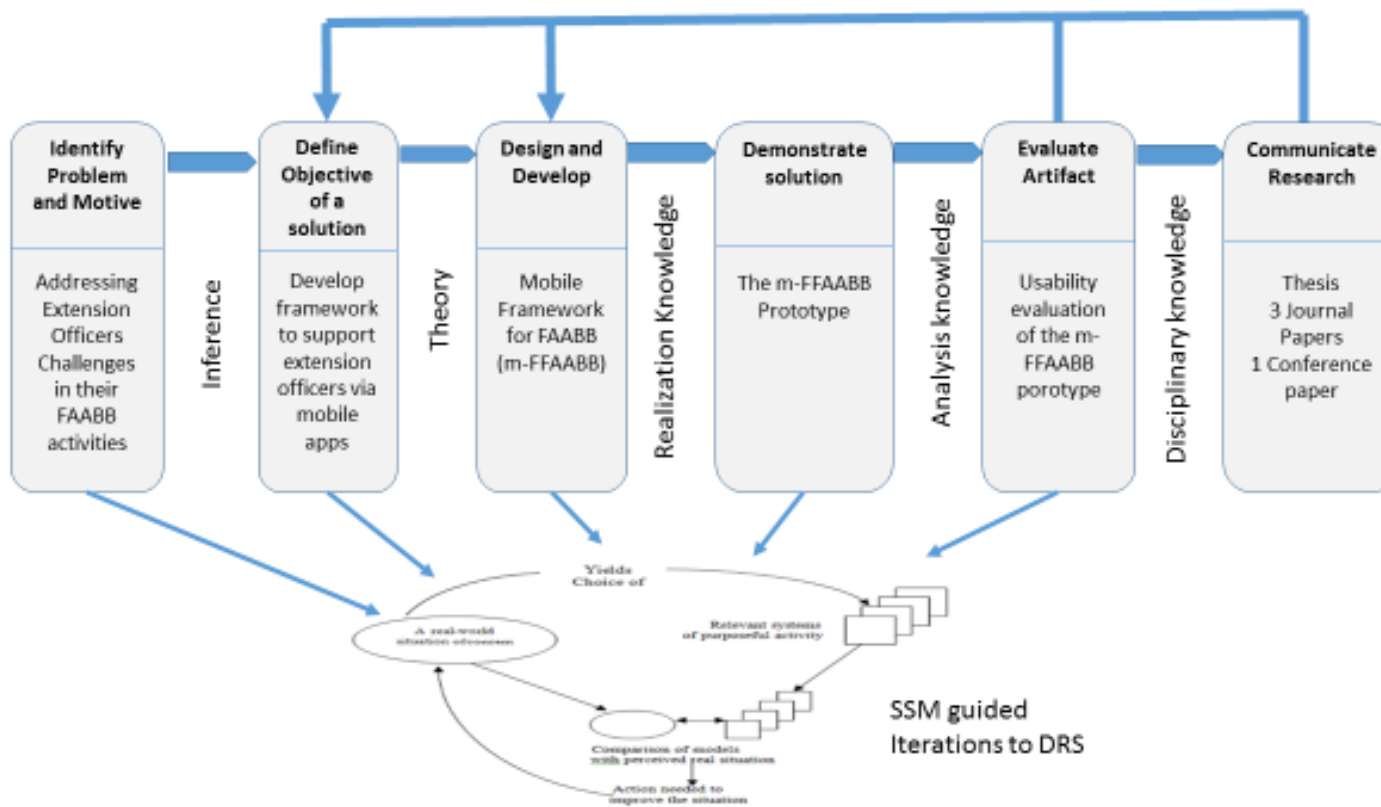
Figure 32: The Design Science Research via Soft System Methodology Process of this Research

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Appendix 1: Nelson Mandela African Institution of Science and Technology RESTful API for External Benchmarking

AI.1 From Farmers Module

(a) Query single farmer by ID

API call: **'/prototype/api/farmer/{id}', GET**

Example JSON Data:

{"id": 343,"created_at": "2018-07-13 15:21:29","updated_at": "2018-07-13 15:21:53","first_name": "blayson","middle_name": "n/a","sur_name": "milinga", "gender": "Male","date_of_birth": "n/A","phone_number": "n/a","email_address" : "n/a","postal_address": "n/a","physical_address": "n/a","house_size": "6"," marital_status": "TBD","region_id": "34","district_id": "140","ward_id": "306 ","village_id": "12","group_id": "206","registration_date": null,"group_regis tration_number": null,"crop_id": "2","farmer_id": "34140306122065266","land_s ize": "37","soil_condition": "N/A","latitude": "N/A","longitude": "N/A","user _id": null,"lead_id": null}

(b) Create Farmer

API call: **'/prototype/api/farmers/farmer/create', POST**

Example JSON Data

{first_name": "blayson","middle_name": "n/a","sur_name": "milinga","gender": " Male","date_of_birth": "n/A","phone_number": "n/a","email_address": "n/a","po stal_address": "n/a","physical_address": "n/a","house_size": "6","marital_sta tus": "TBD","region_id": "34","district_id": "140","ward_id": "306","village_ id": "12","group_id": "206","registration_date": null,"group_registration_num ber": null,"crop_id": "2","farmer_id": "34140306122065266","land_size": "37", "soil_condition": "N/A","latitude": "N/A","longitude": "N/A","user_id": null, "lead_id": null}

(c) Delete Farmer by ID

API call: **'/prototype/api/farmers/farmer/delete/{id}', DELETE**

(d) Edit Farmer by ID

API call: **'/prototype/api/farmers/farmer/edit/{id}', PUT**

Example JSON Data

{"id": 343,"created_at": "2018-07-13 15:21:29","updated_at": "2018-07-13 15:21:53","first_name": "blayson","middle_name": "n/a","sur_name": "milinga", "gender": "Male","date_of_birth": "n/A","phone_number": "n/a","email_address" : "n/a","postal_address": "n/a","physical_address": "n/a","house_size": "6"," marital_status": "TBD","region_id": "34","district_id": "140","ward_id": "306 ","village_id": "12","group_id": "206","registration_date": null,"group_regis tration_number": null,"crop_id": "2","farmer_id": "34140306122065266","land_s ize": "37","soil_condition": "N/A","latitude": "N/A","longitude": "N/A","user _id": null,"lead_id": null}

(e) Update land details by ID

API call: **'/prototype/api/farmers/farmer/add/land_details/{id}', POST**
Example JSON Data
{"land_size ": "10","longitude": "n/a","latitude": "n/a"," soil_condition ": "n/a}
Returns
Example JSON Data

{"id": 343,"created_at": "2018-07-13 15:21:29","updated_at": "2018-07-13 15:21:53","first_name": "blayson","middle_name": "n/a","sur_name": "milinga", "gender": "Male","date_of_birth": "n/A","phone_number": "n/a","email_address" : "n/a","postal_address": "n/a","physical_address": "n/a","house_size": "6"," marital_status": "TBD","region_id": "34","district_id": "140","ward_id": "306 ","village_id": "12","group_id": "206","registration_date": null,"group_regis tration_number": null,"crop_id": "2","farmer_id": "34140306122065266","land_s ize": "37","soil_condition": "N/A","latitude": "N/A","longitude": "N/A","user _id": null,"lead_id": null}

(f) Search farmer by UIN, Names, others

API call: **'/prototype/api/farmers/farmer/search', POST**
{"name": "blayson"} Returns
Example JSON Data

[{"id": 343,"created_at": "2018-07-13 15:21:29","updated_at": "2018-07-13 15:21:53","first_name": "blayson","middle_name": "n/a","sur_name": "milinga", "gender": "Male","date_of_birth": "n/A","phone_number": "n/a","email_address": "n/a","postal_address": "n/a","physical_address": "n/a","house_size": "6"," marital_status": "TBD","region_id": "34","district_id": "140","ward_id": "306","village_id": "12","group_id":

"206","registration_date": null,"group_regis tration_number": null,"crop_id": "2","farmer_id": "34140306122065266","land_s ize": "37","soil_condition": "N/A","latitude": "N/A","longitude": "N/A","user _id": null,"lead_id": null}]

(g) AI.2 From Group Module

(h) Get all groups

API call: **'/prototype/api/groups', GET**

Example JSON Data

[{"id": 322,"created_at": "2019-04-10 10:01:05","updated_at": "2019-04-10 10:02:50","name": "Group PXX","registration_number": "12345","registration_date": "2019-0412","chairperson": "Jimy SMith","phone_number": "+255765778866","info": "farmers group","region_id": "14","email": "jimysmith123@example.com","district_id": "35","ward_id": "85","village_id": "32","secretary": "Dee James","secretary_phone_number": "+255765223300", "secretary_email": "deejamme s234@example.com","accountant": "George Johnson", "accountant_phone_number": "+255765992200","accountant_email": "gjoh nson298@example.com"},{"id": 13,"created_at": "2018-08-05 12:42:57","updated_at": "2018-08-05 12:42:57","name": "Twiyendage", "registration_number": "IDC/PTC/34","registrat ion_date": "2016-01-01", "chairperson": "Peter Mbata","phone_number": "+255753770658","info": "The group do not have bank account","region_id": "14","email": "Mbata@gmail.com","district_id": "35","wa rd_id": "434","village_id": "94","secretary": "Aidan sanga","secretary_phone_number": "+255762907811","secretary_email": "Sanga@gm ail.com","accountant": "Gelefasi kenza","accountant_phone_number": "+2555765123343", "accountant_email": "Kenza @gmail.com"},. . .}]

(i) Get group by ID

API call: **'/prototype/api/group/{id}', GET**

Example JSON Data

{"id": 13,"created_at": "2018-08-05 12:42:57","updated_at": "2018-08-05 12:42:57","name": "Twiyendage","registration_number": "IDC/PTC/34","registrat ion_date": "2016-01-01","chairperson": "Peter Mbata","phone_number": "+255753770658","info": "The group do not have bank account","region_id": "14","email": "Mbata@gmail.com","district_id": "35","wa rd_id": "434","village_id": "94","secretary": "Aidan

sanga","secretary_phone_number": "+255762907811","secretary_email": "Sanga@gm ail.com","accountant": "Gelefasi kenza","accountant_phone_number": "+2555765123343","accountant_email": "Kenza @gmail.com"}

(j) Create group

API call: **'/prototype/api/groups/group/create', POST**

Example JSON Data

{"id": 13,"created_at": "2018-08-05 12:42:57","updated_at": "2018-08-05 12:42:57","name": "Twiyendage","registration_number": "IDC/PTC/34","registrat ion_date": "2016-01-01","chairperson": "Peter Mbata","phone_number": "+255753770658","info": "The group do not have bank account","region_id": "14","email": "Mbata@gmail.com","district_id": "35","wa rd_id": "434","village_id": "94","secretary": "Aidan sanga","secretary_phone_number": "+255762907811","secretary_email": "Sanga@gm ail.com","accountant": "Gelefasi kenza","accountant_phone_number": "+2555765123343","accountant_email": "Kenza @gmail.com"}

(a) Edit group by ID

API call: **'/prototype/api/groups/group/edit/{id}', PUT**

Example JSON Data

{"id": 13,"created_at": "2018-08-05 12:42:57","updated_at": "2018-08-05 12:42:57","name": "Twiyendage","registration_number": "IDC/PTC/34","registrat ion_date": "2016-01-01","chairperson": "Peter Mbata","phone_number": "+255753770658","info": "The group do not have bank account","region_id": "14","email": "Mbata@gmail.com","district_id": "35","wa rd_id": "434","village_id": "94","secretary": "Aidan sanga","secretary_phone_number": "+255762907811","secretary_email": "Sanga@gm ail.com","accountant": "Gelefasi kenza","accountant_phone_number": "+2555765123343","accountant_email": "Kenza @gmail.com"}

(b) Delete by ID

API call: **/prototype/api/groups/group/destroy/{id}', DELETE**

AI.3 From Crops Module

(a) Get all crops

API call: **'/prototype/api/crops', GET**

Example JSON Data

[{"id": 5,"created_at": "2019-04-10 10:21:56","updated_at": "2019-04-10 10:23:45","name": "test Crop","yield_per_acre": "5","time": "3","seed_spacing": "2c","weather_conditi on": "winter","soil_condition": "moist soil","info": "moist soil"},{"id": 4,"created_at": "2018-08-06 13:09:38","updated_at": "2018-08-06 13:09:38","name": "Paddy","yield_per_acre": "N/a","time": "N/A","seed_spacing ": "N/A","weather_condition": "N/A","soil_condition": "N/A","info": "N/A"}, . . .]

(b) Get crop by ID

API call: **'/prototype/api/crops/{id}', GET**

Example JSON Data

{"id": 5,"created_at": "2019-04-10 10:21:56","updated_at": "2019-04-10 10:23:45","name": "test Crop","yield_per_acre": "5","time": "3","seed_spacing": "2c","weather_conditi on": "winter","soil_condition": "moist soil","info": "moist soil"}

(c) Create crop

API call: **'/prototype/api/crops/crop/create', POST**

Example JSON Data

{"id": 5,"created_at": "2019-04-10 10:21:56","updated_at": "2019-04-10 10:23:45","name": "test Crop","yield_per_acre": "5","time": "3","seed_spacing": "2c","weather_conditi on": "winter","soil_condition": "moist soil","info": "moist soil"}

(d) Update crop by ID

API call: **'/prototype/api/crops/crop/edit/{id}', PUT**

Example JSON Data

{"id": 5,"created_at": "2019-04-10 10:21:56","updated_at": "2019-04-10 10:23:45","name": "test Crop","yield_per_acre": "5","time": "3","seed_spacing": "2c","weather_conditi on": "winter","soil_condition": "moist soil","info": "moist soil"}

(e) Delete crop by ID

API call: **'/prototype/api/crops/crop/destroy/{id}', DELETE**

RESEARCH OUTPUTS

The following are claimed as original research outputs from the reported research:

Research Output 1: Artifacts from the Research Work

(i) *The Framework:* The m-FFAABB is the first study based on an integrated and holistic approach   addressing all stages of the FAABB decision process, while existing studies in the literature focus on specific stages. As the main artifact of this research, the primary contribution is the proposed m-FFAABB framework. The present study provides the required components of a mobile information system to be designed to support farmers in the decision process. Not only the facilitating components, but also the unifying ones are incorporated into m-FFAABB enabling utilization of more information compared to stand-alone solutions. The integrated and holistic approach provided by these components contributes to the body of knowledge in the area of mobile information systems for ARD (i.e. m-ARDs).

(ii) *The API:* The proposed API that provides a framework for data representation and communication between the mobile apps and the FAABB business logic is also an artifact of this research, and contributes to the body of knowledge of the knowledge codification and external benchmarking domains. A RESTful API supporting JSON is presented as a lightweight data-interchange format between the servers hosted at CREATES and mobile apps developing platform at client side. Since JSON is a text format that is completely language independent but uses conventions that are familiar to programmers, it enables the realization of external benchmarking as a service to be provided by CREATES. These properties make JSON an ideal data-interchange language. The proposed JSON driven API tools and their embedded notations are other contributions of this research.

(iii) *The m-FFAABB Prototype:* The prototype   of the m-FFAABB   framework   is developed to show the applicability and benefits of the framework. Experiments were also conducted to evaluate the prototype. According to the results of the usability test, EOs found the features of the prototype useful, and the system easy to use. EOs agreed to use the prototype frequently, and they stated that the functions of the prototype are well integrated.   These   results   show   that the external benchmarking   approach   of m-FFAABB is applicable. Moreover, statistical analysis of the task completion times and selection errors prove that the prototype is

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time and cost saving, and reduces the intellectual effort of conducting benchmarking by EOs.

(iv)   *The m-ARD Prototypes as Instances of m-FFAABB:* The two m-ARD prototypes, one addressing the needs of crops sub-domain and the other addressing the livestock (dairy) sub-domain, are instantiations of m-FFAABB, and show applicability and feasibility of the framework. The first prototype concentrated on crop domain targeting rice and rice products.   The two developed prototypes are to be regarded as a proof of concept and not a fully functional implementation. The framework for the integration of the two prototypes is also provided through an ambitious big data infrastructure establishment at NM-AIST to support the framework. The evaluation of the developed prototype shows that such an approach provides benefits to EOs by enabling utilization of more information compared to stand-alone solutions developed for individual stages.

Taken together, these results demonstrate that m-FFAABB has the potential to provide support for the farming decision process to the benefit of EOs in assisting smallholder farmers to conduct FAAB via external benchmarking, and also highlight that such mobile information systems address the challenges experienced by EOs. The research work includes both technology-oriented (e.g., mobile information systems) and management-oriented (e.g., FAABB process) concepts. Although the primary audience of this research is IT-oriented academics, it is also relevant to agribusiness-oriented specialists and practitioners and CREATES researchers. This research also reveals that such a solution has intensive data requirements, and demonstrates the importance of external benchmarking through knowledge codification at a dedicated repository hosted by CREATES at NM-AIST in the context of supporting EOs on their external benchmarking activities.

Research Output 2: Publications

The primary communication of this research is this PhD thesis, which is a detailed and comprehensive piece of communication of the research work. In addition, three published journal papers are additional communications of this research as follows:

Kyaruzi, J. J., Yonah, Z. O., & Swai, H. S. (2019). Review of Agricultural and Rural Development System Models and Frameworks to Support Farming as a Business via Benchmarking: The Case of Tanzania. *International Journal of Computing and*

Digital Systems. 8(6), 576-585. *ISSN (2210-142X)* http:// dx. doi. org/ 10. 19101/ IJACR. 019. 94007.

Kyaruzi, J. J., Yonah, Z. O., & Swai, H. S. (2019). Mobile application development framework to support farming as a business via benchmarking: The case of Tanzania. *International Journal of Advanced Computer Research,* 9 (45), 365-378. ISSN (Print): 2249-7277 ISSN (Online): 2277-7970 http: //dx. doi. org/ 10. 19101/ IJACR. 2019. 940074.

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Research Output 3: Poster Presentations