UNIVERSITY OF KWAZULU-NATAL

Livestock Identification and Tracking System for Controlling Livestock Theft: Case Study of South Africa

By

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A thesis submitted in fulfilment of the requirements for the degree of

Doctor of Business Administration

Graduate School of Business and Leadership

College of Law and Management Studies

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3 September 2024

Declaration

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Acknowledgements

Firstly, I would like to thank the Lord, Almighty God.

My appreciation is extended to my supervisor, Professor Stephen Mutula, for his guidance.

My appreciation is extended to Professor Fayth Ruffin for language editing.

My appreciation is extended to the UKZN UCDP for their financial support.

My appreciation is extended to my parents, thank you for encouraging me to study.

My late grandmother, this is dedicated to you.

Lastly and most importantly, my sons and daughter, this is dedicated to you.

Abstract

This thesis explores livestock theft problem within the South Africa context, focusing on cattle, sheep, and goats, and evaluates the potential of Information and Communications Technologies (ICTs) to address this critical problem. Conventional identification and tracking methods are currently ineffective, prompting the need for ICT based solutions. Despite calls for ICT intervention, no comprehensive conceptual model exists for South Africa. This study aims to fill this gap by proposing an ICT-based national livestock identification and tracking system to control livestock theft in South Africa. Utilizing Actor-Network Theory and a qualitative approach, the research includes interviews and questionnaires with stakeholders such as farmers, police, and stock theft forums. The study also integrates secondary data and literature, supported by a Scoping Review, snowball strategy, PRISMA method, and CASP framework. Data analysis employed thematic and content analysis techniques. Findings reveal that livestock theft networks are well-organized, highlighting the need of a unified national ICT based solution to combat livestock theft. The study identifies several potential ICT tools such as mobile phones, biometric technology, radio and TV broadcasting, camera traps, cloud computing, and drones as viable solutions. The proposed conceptual model of a national livestock identification and tracking system features two modules: retinal pattern-based biometric identification and three tracking methods. A Design Science Research Methodology (DSRM) framework was used to present the conceptual model for the proposed system. Recommendations emphasize the need for collaboration among stakeholders, including the Department of Agriculture, South African Police Service, and State Information Technology Agency. Limitations include a focus on the top ten livestock theft-hotspots and reliance on secondary data, with suggestions for future research to involve direct data collection from additional informants and explore how perpetrators use ICTs. The study contributes empirical insights and presents a practical model for controlling livestock theft through ICTs, along with a business case for its implementation. Future research should address the political implications and technical details of the ICT solution, as the current study does not cover the implementation process.

Keywords: Livestock theft; Information and Communication Technologies; Actor-Network Theory; Design Science Research Methodology; Retinal patterns; Livestock tracking; Livestock identification; South Africa

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List of Acronyms and Abbreviations

Acronyms and Abbreviations	Meaning
3G	Third Generation (of mobile networks)
4G	Fourth Generation (of mobile networks)
5G	Fifth Generation (of mobile networks)
Agribook	Agricultural Book
AgriTech	Agricultural Technology
AgriTV	Agricultural Television
AIRT	Animal Identification, Recording, Traceability, and Tracking
AIS	Animal Identification System
ANT	Actor-Network Theory
ARC	Agricultural Research Council
DALRRD	The Department of Agriculture, Land Reform and Rural Development
DAFF	Department of Agriculture, Forestry, and Fisheries
DNA	Deoxyribonucleic Acid
DOI	Diffusion of Innovations
DSRM	Design Science Research Methodology
e-agriculture	electronic agriculture
et al.	et alia (and others)
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GPS	Global Positioning System
GSMA	Global System for Mobile Communications
ICASA	Independent Communications Authority of South Africa
ICTs	Information and Communications Technologies
IoT	Internet of Things
IS	Information Systems
IT	Information Technology
ITU	International Telecommunication Union
IVR	Interactive Voice Response

Acronyms and Abbreviations	**Meaning**
LPWAN	Low-Power Wide-Area Network
MMS	Multimedia Messaging Service
NGO	Non-Governmental Organization
NSPCA	National Council of Societies for the Prevention of Cruelty to Animals
PESTEL	Political Economic Social Technological Environmental Legal
RFID	Radio Frequency Identification
SAPS	South African Police Service
SWOT	Strengths Weakness Opportunities Threats
SMS	Short Message Service
StatsSA	Statistics South Africa
TAM	Technology Acceptance Model
TTF	Task-Technology Fit Theory
TV	Television
USSD	Unstructured Supplementary Service Data
UTAUT	Unified Theory of Acceptance and Use of Technology
VoIP	Voice Over Internet Protocol
WOAH	World Organization for Animal Health

CHAPTER 1

CONTEXT OF THE STUDY

1.1. Introduction

This research is a case study of South Africa. The study addresses the scales and dimensions of livestock theft within the South African context. Livestock theft is one of the major problems facing the livestock sector in South Africa (Matiwane & Matiwane, 2021; Geldenhuys, 2020; Clack, 2018; STPF, 2014; Meissner et al., 2013; PMG, 2010). The South African Police Service (SAPS) crime statistics show that theft of livestock is prevalent in all nine provinces of the country, making it a national problem (SAPS, 2022). Cross-border livestock theft from South Africa into neighbouring countries such as Lesotho, Swaziland and Mozambique make it a regional issue (PMG, 2020; Stock Theft Preventative Forum, 2015). Livestock theft has a devastating socio-economic and cultural impact on the country. For instance, it is estimated that the country`s livestock farming sector loses more than R800 million annually due to livestock theft (STPF, 2014).

The challenges of identifying and tracking stolen livestock exacerbate livestock theft in South Africa (Cilliers, 2019; Lombard & van Rooyen, 2017). This is due to the ineffectiveness of conventional, mechanical and traditional methods such as ear tags, manual registers, and brand marks. For instance, thieves can readily change the appearance of stolen livestock by dehorning livestock, removing ear tags, or smudging brand marks. This makes it difficult to identify, track and recover the stolen livestock. This makes it difficult to prevent, mitigate or control livestock theft. The conventional methods make it difficult for law enforcement officials to link the livestock to the original owner or to a particular farm if and when the livestock is recovered. To overcome the livestock identification and tracking challenges, this study examines Information and Communications Technologies (ICTs) as strategic tools for controlling livestock theft.

In the context of this study, the term ICTs is used as an umbrella term to encompass all electronic devices, telecommunications, networking components, services, databases, applications and systems that enable users to capture, access, store, transmit, analyse, and manipulate information. ICTs include traditional means of communication such as TV broadcasting, radio broadcasting, and two-way radio networks. ICTs also include technologies fueling Fourth Industrial Revolution (4IR) such as cloud computing, Fifth Generation (5G) networks, Internet of Things (IoT), blockchain, big data, drones, 3D printing, augmented reality, virtual reality, mixed reality, artificial intelligence, and robotics.

Farmers alone cannot control livestock theft. As with any national problem, a multi-stakeholder approach is required. In support of this argument, Bunei (2017, p.10) avers that

> "A salient feature of the more successful sustainable stock theft prevention strategy is to have a close and concerted partnership-based collaboration, interaction and information exchange. The integrated approach should include a number of stakeholders such as farmers, law enforcers, business communities, different government institutions and research institutions. Farmers should be ready to work proactively with their neighbours, community and the police. It is essential that law enforcement agencies collaborate to deal with all stock theft consistently. This principle of an integrated approach is maintained at both community and national levels".

This research applies a holistic approach to explore how livestock stakeholders can utilise ICTs to control livestock theft in the South African context. The term 'livestock stakeholders' refers to livestock farmers, government, stock theft preventative forums, communities, traditional authority, industry organizations, and other relevant structures. The holistic approach to the study generated a strategic model for ICT-based livestock identification and tracking system to control livestock theft in South Africa.

This thesis consists of this chapter (chapter 1), a chapter on theoretical framework, three literature review chapters, a methodology chapter, a chapter on data analysis, findings and discussions, a chapter for the proposed solution, and a final chapter that covers conclusion and recommendations. The detailed structure of the thesis is presented in section 1.9 of this chapter.

1.2. Background to the Study

Although livestock theft is not a new phenomenon, recently the frequency and intensity of the practice has reached uncontrollable levels. Across Africa and more specifically South Africa, livestock theft is a persistent problem, posing a serious threat to food security and livelihood development (Clack, 2020; Bunei et al., 2016; Manu et al., 2014; Clack, 2013). In the South African context, cattle, sheep and goats are the major targets of theft due their significant socio-economic value (Lombard, 2020). It is reported that cattle, sheep and goats comprise roughly

87% of all livestock stolen in South Africa. Several research studies revealed that livestock theft is a ‘big business’ in South Africa. It has transformed from petty theft by individuals to large-scale operations conducted by organised syndicates (Clack, 2018). Organised syndicates do not just steal one or two animals. Rather, they steal a group of animals which are transported with trucks and vans (Stock Theft Preventive Forum, 2015; Famer`s Weekly Magazine, 2015a). In South Africa, all livestock farmers (smallholder, subsistence, emerging and large-scale commercial farmers) are the victims of livestock-theft. There is a lacuna of South African-based research on combating, controlling, or mitigating livestock theft. Existing research problematises the ineffectiveness of law enforcement, lack of trust in relevant authorities, analysis of livestock theft cases, and impact of livestock theft on farming communities. There is little research on exploring the role and use of ICTs in controlling livestock theft.

The negative impact of livestock theft goes far beyond livestock farmers and farms. The debilitating impact directly cascades to the socio-cultural ecosystem, economic ecosystem, and political ecosystem. Economically, livestock theft has a negative impact on the primary sector (agriculture), secondary sector (agro-processing), exports, food security, incomes and employment. Socially and politically, livestock theft can lead to tensions, violence and war amongst the affected communities. Livestock theft has a negative impact on the South African cultural stability; since some livestock such as cattle, goats and sheep are used for cultural traditions such as ‘lobola’, rituals, and ceremonies. The scourge of livestock theft could lead to uncontrollable animal diseases across the country and region. Livestock are at times stolen from one province and then illegally sold in another province. Such cross-border livestock theft could contribute to livestock disease outbreaks.

Research on ICTs in agriculture (e-agriculture) in the context livestock identification and tracking to control livestock theft has been carried out in different parts of the word. The research on ICTs in agriculture have been about IoT, cloud computing, big data and analytics, drones, mobile applications, open source software, mobile phones, internet connectivity, text (SMS) based service, and radio frequency identification. For instance, studies on IoT and livestock have been conducted by many scholars such as Imtihan et al. (2021), Joshitha et al. (2021), Priyanka (2019), Joshitha et al. (2021), Ojo et al. (2021), Stojkoska et al. (2018), Gbemisola et al. (2018), Stojkoska et al. (2018), Saravanan & Saraniya (2018), Abdullahi et al. (2019), Dieng et al. (2017), and Wamuyu (2017). Specially, Alanezi et al. (2022) discussed the potential of drones for mapping and monitoring livestock. However, in South Africa there is limited research in the context of ICT-based livestock identification and tracking technologies and systems to mitigate/control livestock theft. Moreover, there is limited research on ICTs as a strategic solution towards resolving the problem of livestock theft in South Africa.

Weaknesses of the traditional animal recognition methods such as ear-tagging, freeze-branding, ear-tattoos, embedded microchips, ear tips or notches-based have led to the emergence of research on electronic animal recognition methods. These include Radio Frequency Identification (RFID) transponders, Global Positioning System (GPS) collars, IoT collars, RID tags/buttons, RFID ruminal bolus, and RIF neck collars. For instance, there is an abundance of research within the 'theme' of electronic animal recognition methods, as research by Bai et al. (2017), Rutter (2017), Wamuyu (2017), Ismail & Ismail (2016), Ibrahim (2016), Roberts (2016), Ekuam (2014), Mutua (2014), Tangorro et al. (2013), Vlad et al. (2012), Ruiz-Garcia & Lunadei (2011), Voulodimos et al. (2010), Bowlling et al. (2008), and Trevarthen (2007). Yet, research on electronic animal recognition methods towards addressing the problem of livestock theft in the context of South Africa is still limited.

Both traditional and electronic animal recognition methods can be invasive to the livestock (Kumar & Singh, 2020). These methods are vulnerable to losses of RFID/GPS tags, easy duplication, and fraud of embedded tag number. A number of research studies have raised concerns of security issues and challenges for the identification of animals using electronic recognition methods (Awad, 2016). These issues and challenges led to the emergence of research on animal biometrics. The potential of biometric technology for animal identification and tracking was researched by Kumar & Singh (2020), Kumar & Singh (2017), Kumar et al. (2016), Tharwat et al. (2015), Lu et al. (2014), Award et al. (2013), Jain et al. (2011), Barron et al. (2009) and Corkery (2007). Research on animal biometric systems towards addressing the problem of livestock theft in the context of South Africa is still limited.

A number of nations have implemented their own ICT systems to deal with livestock management. Currently, nations such as Botswana, Namibia, Mongolia, Malaysia, Australia, United States of America (USA), and Brazil have their own ICT-based National Livestock Identification and Tracking/Tracing Systems to capture, store and report animal details, animal movements and farmers details (Bowling et al., 2008; Murphy et al., 2008). However, the motive behind the implementation of such systems in the above-mentioned nations has been largely driven by supply chain issues. This does not address the problem of livestock-theft. For example, Australia, Botswana, and Namibia export beef to the lucrative EU markets, and the EU regulations require that beef be traceable back to the individual animal of origin and that a computerized central system be established. Another factor that prompted these nations to develop such systems is the motive to monitor livestock disease outbreaks. The South African economy, livestock farming sector dynamics, culture, technological developments, and demographics differ from the above-mentioned nations.

In South Africa, there is an Animal Identification System (AIS). AIS is a national register of official animal identification marks. All livestock farmers/owners in South Africa are required to apply for official identification marks. They are further obligated to then brand their livestock with official identification marks, as prescribed by the Animal Identification Act 2002 (South African Government, 2015; National Stock Theft Forum, 2015). AIS has many limitations, these limitations include: (i) the process of registering animal identification marks is semi-manual, in the sense that livestock holders have to manually send hard-copy forms to Pretoria (capital city of South Africa); (ii) in any manual or semi-manual system, a number of mistakes are often experienced during the information transfer process due to the manual entry of information from the forms; (iii) AIS does not capture, record and report animal movements; (iv) the system does not capture, record and report individual animal unique identifications; (iv) it is relatively easy for the thieves to tamper with identification marks; and (v) it is only the South African Police Service that have access to the system. Therefore, AIS is limited in terms of livestock identification and tracking towards controlling livestock theft in South Africa.

The absence of integrated modern technologies such as mobile technology, cloud computing, artificial intelligence, GPS, social media, drone technology, machine learning algorithms, and business intelligence reporting contribute to the ineffectiveness. According to Department of Agriculture, Land Reform and Rural Development (2015), South Africa does not have an ICT-based Integrated and Comprehensive Animal Identification, Recording and Traceability and Tracking (AIRT) system to benefit farmers, consumers, and the nation as a whole. Nor does South Africa have a model of an AIRT system. To overcome these outlined research gaps including the lack of an AIRT in South Africa, this study therefore proposes a strategic model of a national holistic livestock identification and tracking system to control livestock theft in South Africa.

In South Africa, in the fight against livestock theft, there are various structures and programmes such as Stock Theft Units (STUs), Stock Theft Preventative Forums, Stock Theft Information Centers, and Rural Safety Strategy. Similarly, there are existing laws such as the

Movement of Animals Bill, Animal Identification Act, Stock Theft Act, Fencing Act, Livestock Improvement Act, and Trespassers Act. Despite these existing structures, programmes and laws, the scourge of livestock theft continues to escalate in South Africa. The potential of ICT utilization by multi-stakeholders as a strategic approach towards resolving the problem of livestock theft in South Africa has not been explored. Based on the background information presented, the researcher was motivated to embark on this study. The Figure 1 below depicts the motive for the study.

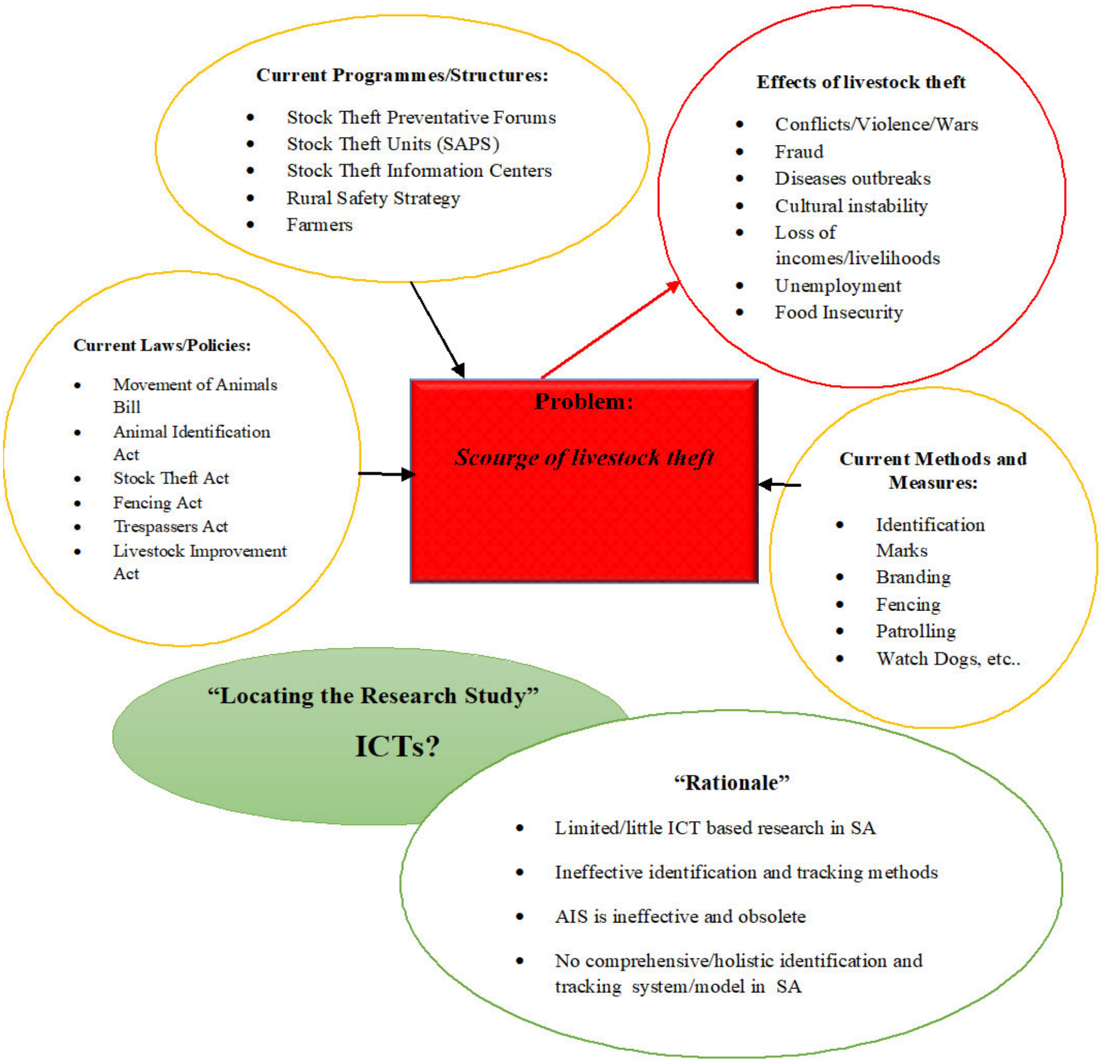


Figure 1: Factors impacting livestock theft.
Source: Author`s illustration

1.3. Statement of the Problem

Livestock theft is one of the biggest and persistent problems facing livestock farmers in South Africa. Between 2016 and 2017, livestock theft crimes in South Africa comprised about 11% of all theft related crimes (StatsSA, 2017). In 2021, more than 29 000 recorded cases of livestock theft in the country were reported by the SAPS. It is estimated that the South African livestock farming sub-sector lost about R750 million in 2013 through livestock theft (Farmer's Weekly Magazine, 2014). Between the year 2016 and 2017, it is estimated that more than 80 000 sheep, more than 30 000 goats and more than 50 000 cattle were stolen (Clack, 2018). Cross-border livestock theft is prevalent in KwaZulu-Natal, Free State, Limpopo and Eastern Cape of the nine provinces of south Africa (Farmer`s Weekly Magazine, 2020; PMG, 2020).

Controlling livestock theft remains one of the biggest challenges facing the livestock farming sector in the country, due to poor livestock identification methods. This argument is supported by Moolman (2017, p.8) when he states: "The combatting of livestock theft is especially hampered by the lack of effective identification". This statement concurs with Red Meat Organisation (2014) which states that

> "Another matter that needs to be explored is the issue of brand mark registration by the Department of Agriculture, Fisheries and Forestry (DAFF) which anyone can register a brand mark. Accordingly, there is no system to verify if a person owns livestock or not and anyone can easily register a brand mark on behalf of someone else. The DAFF should remove all outdated brand marks from the record and to explore the possibility of obligating livestock owners to renew their brand marks every five years".

Positive identification of livestock remains one of the biggest challenges in controlling livestock theft and recovery of stolen livestock in South Africa. This is because conventional methods such as temporal marks and permanent marks are tedious and prone to fraud, can be easily tampered with, and are often not individual-animal specific. Conventional livestock identification methods also make it difficult to track stolen, lost, missing or stray livestock.

The scourge of livestock theft and ineffectiveness of conventional livestock identification methods has prompted cross-sector stakeholders to 'call' for the utilization of ICTs in the fight against livestock theft. These include governments, famers, not-for-profit organisations (NGOs) and industry organisations. Some research studies on livestock theft recommend the strategic investment in technology and use of ICTs to fight livestock theft. For example, in 2010 the South African Ministry of Agriculture and various livestock stakeholders held a meeting on 'Stock Theft in South Africa'. The focus highlighted the need for ICT-based solutions in addressing the livestock theft problem in South Africa (PMG, 2020; PMG, 2010). The South African Ministry of Agriculture believes that livestock theft in South Africa could be reduced by having a livestock identification and traceability system (DALRRD, 2018). Similarly, the promotion of electronic identification and tracking systems have emerged elsewhere in Africa. For instance, in 2014 the International Livestock Institute together with Kenyan and Ugandan livestock stakeholders held a workshop on livestock identification and traceability in Uganda. Once again, the focus highlighted the need for ICTs based solutions in addressing livestock theft (Mutua, 2014).

Outside of South Africa, research studies on ICT-based livestock identification and tracking has been conducted. However, most of the research studies do not consider the specific socio-economic and cultural contexts of farmers, including, language diversity, low incomes, literacy levels, and adaptation to local contexts. The majority of studies focus on farmers as being the key stakeholders for combating livestock theft; without considering other stakeholders such as law enforcement agencies and community forums. Most of the proposed ICT-based solutions lack empirical data and business case studies to support their feasibility, effectiveness, and cost-benefit analysis.

Commercial solutions such as mobile apps integrated with GPS trackers exist and being are promoted on the markets. In South Africa, the iSi-WATCH system is an example of a commercial solution that uses IoT devices to track and monitor various livestock, including, but not limited to cattle, sheep and rhino (isiTech, 2024). The existing commercial solutions have many limitations. They are mostly targeted at commercial farmers for use at farm level. They do not cater for other livestock stakeholders, despite livestock theft being a national problem requiring multi-stakeholder involvement. Additionally, the existing commercial solutions lack the capacity to handle large volumes of data. Lastly, the high costs of GPS trackers, IoT devices and IoT gateways, required by some software for livestock tracking, make them impractical for communal farmers, where livestock farmers are characterised by low incomes. These GPS trackers and IoT trackers are also vulnerable to being easily removed by thieves.

In the South African context, despite the aforementioned need for livestock theft to be sufficiently addressed through the utilization of ICTs, this topic has attracted little attention among researchers in the Information Systems (IS) field. Particularly, the use of ICTs as a potential solution to the problem of livestock theft is under-studied. In South Africa, most research studies have been carried out on the effect of livestock theft from an economic, social and cultural perspective. Similarly, there has been research on factors that contribute to livestock theft in South Africa. However, research on the use of ICTs to control livestock theft in South Africa has not been given much attention. This is despite the significant losses associated with livestock theft in South Africa. The current study focuses on redressing the problem of livestock theft by exploring ways in which livestock stakeholders can utilise ICTs to control livestock theft in the South Africa. It is for this purpose that the study proposes a model of an ICT-based livestock identification and tracking system for controlling livestock theft in South Africa.

1.4. Aims and Goals of the Study

According to FAO (2017), ICT can assist the agricultural sector by providing reliable and valuable answers to the problems the sector is currently facing. Globally, one of the problems facing the agricultural sector is theft of livestock. This study 'looks into' ICTs as a strategic approach for controlling the problem of livestock theft in South Africa. Controlling livestock theft requires interconnected information systems at the farm and the national level and across stakeholders in the value chain factors affecting the occurrence of livestock theft under South African conditions.

The study is therefore aimed at exploring how livestock stakeholders (livestock farmers, government, communities, traditional authority, industry organizations, and other relevant stakeholders) can utilise ICTs to control livestock theft in South Africa. Furthermore, the goal of this study is to propose a national comprehensive and holistic model of a livestock identification and tracking system that controls livestock theft in South Africa.

1.5. Research Objectives

The research objectives of this study are to:

1) understand the nature, prevalence and dynamics of livestock theft in South Africa.
2) identify the important human actors involved in the fight against livestock theft in South Africa.
3) explore the role of human actors and their relations for controlling livestock theft in South Africa.

4) review the nature and extent of use of livestock identification methods and tracking methods by the human actors for controlling, mitigating and combating livestock theft in South Africa.
5) ascertain the ICTs that have been adopted by the human actors involved in the fight against livestock theft in South Africa.
6) find out the suitable, available and effective ICTs that can be used for livestock identification and tracking to control livestock theft South Africa.
7) determine the insights, attitudes and perceptions of research participants towards the use of ICTs for controlling livestock theft in South Africa.
8) examine the information system components required to develop a national-wide holistic livestock identification and tracking system for controlling livestock theft in South Africa.

1.6. Research Questions

To both explore the use of ICTs and to propose a system to control livestock theft, a number of questions specific to the South African socio-economic environment were posed, this study is guided by the following primary research question and sub-questions.

Primary research question: According to Bunei (2017, p.10), "Livestock theft is a global problem, and farmers alone cannot solve it; the problem needs a close and concerted partnership-based collaboration, interaction and information exchange among various stakeholders". The knowledge inputs, requirements and the use of ICT tools by various stakeholders may differ in the fight against livestock theft. Therefore, this study is guided by this primary research question: how can livestock stakeholders (livestock farmers, government, communities, traditional authorities, industry organizations, and other relevant stakeholders) utilise ICTs to control livestock theft in South Africa? From this perspective, the following sub-research questions are addressed:

Sub-questions:

1) How does livestock theft occur in South Africa?
2) Who are the important actors involved 'in the fight against' livestock theft in South Africa?
3) How can the important actors be organized to control livestock theft in South Africa?

4) What is the nature of use of livestock identification methods and tracking methods by the human actors for controlling, mitigating, or combating livestock theft in South Africa?
5) Which ICTs have been adopted by the human actors involved 'in the fight against' livestock theft in South Africa?
6) What are the suitable, available and effective ICTs that can be used for livestock identification and tracking in order to control livestock theft in South Africa?
7) What are the insights, attitudes and perceptions of research participants towards the use of ICTs for controlling livestock theft in South Africa?
8) What are the information system components required to develop a holistic and national livestock identification and tracking system for controlling livestock theft in South Africa?

1.7. Methods

All the aspects of methodology described below are discussed in detail in the methodology chapter (chapter 6).

Research Type: There are four major types of research, namely: laboratory research, field research, basic/fundamental research and applied research. The type of research for this study is basic research with some elements of applied research.

Research Design/Strategy: The research design/strategy adopted in this research study is a combination of case study and Design Science Research Methodology (DSRM). The DSRM is elaborated upon in chapter eight.

Philosophy/Paradigm: A paradigm is a basic belief system and theoretical framework with assumptions about ontology, epistemology, methodology, and methods. Types of research paradigms include positivism, interpretivism, and critical theory (Rehman & Alharthi 2016; Saunders et al., 2007). The research study adopted interpretivism as the research paradigm.

Research Approach: A qualitative approach was found suitable for this study, because the primary focus of qualitative approach is on understanding and interpreting the meanings, perspectives, and experiences of individuals or groups within a specific context. Qualitative approach involves collecting and analysing non-numerical data in form of text, audio, images, or video.

Data Collection Methods and Procedures: Primary data were collected using interviews and questionnaires. Primary data were supplemented by literature analysis and information from secondary sources.

Research Participants: There were 63 research participants in the research study.

Sampling: Both purposive and convenience sampling techniques were used to select the research participants. In purposive sampling, the researcher intentionally selects participants based on their characteristics, knowledge, experiences, or some other criteria. In convenience sampling, the researcher recruits participants based on their availability, accessibility and willingness to participate in the study. These two sampling techniques are based on a non-probability sampling method for qualitative research.

Data analysis: Data were analysed using two methods: thematic analysis and content analysis. These two methods are 'inline' with the research approach of the study: qualitative approach. They are also 'inline' with the data collection methods implemented in the study.

Proposed Model: A livestock identification and tracking system model for controlling theft of livestock in South Africa was developed using Design Science Research Methodology (DRSM). A business case for the proposed solution is also provided.

The methodological approach for this study is illustrated in Figure 2 below (a framework for research). The aspects in Figure 2 are discussed in detail in Chapters Two, Three, Four, Five, Six, Seven and Eight.

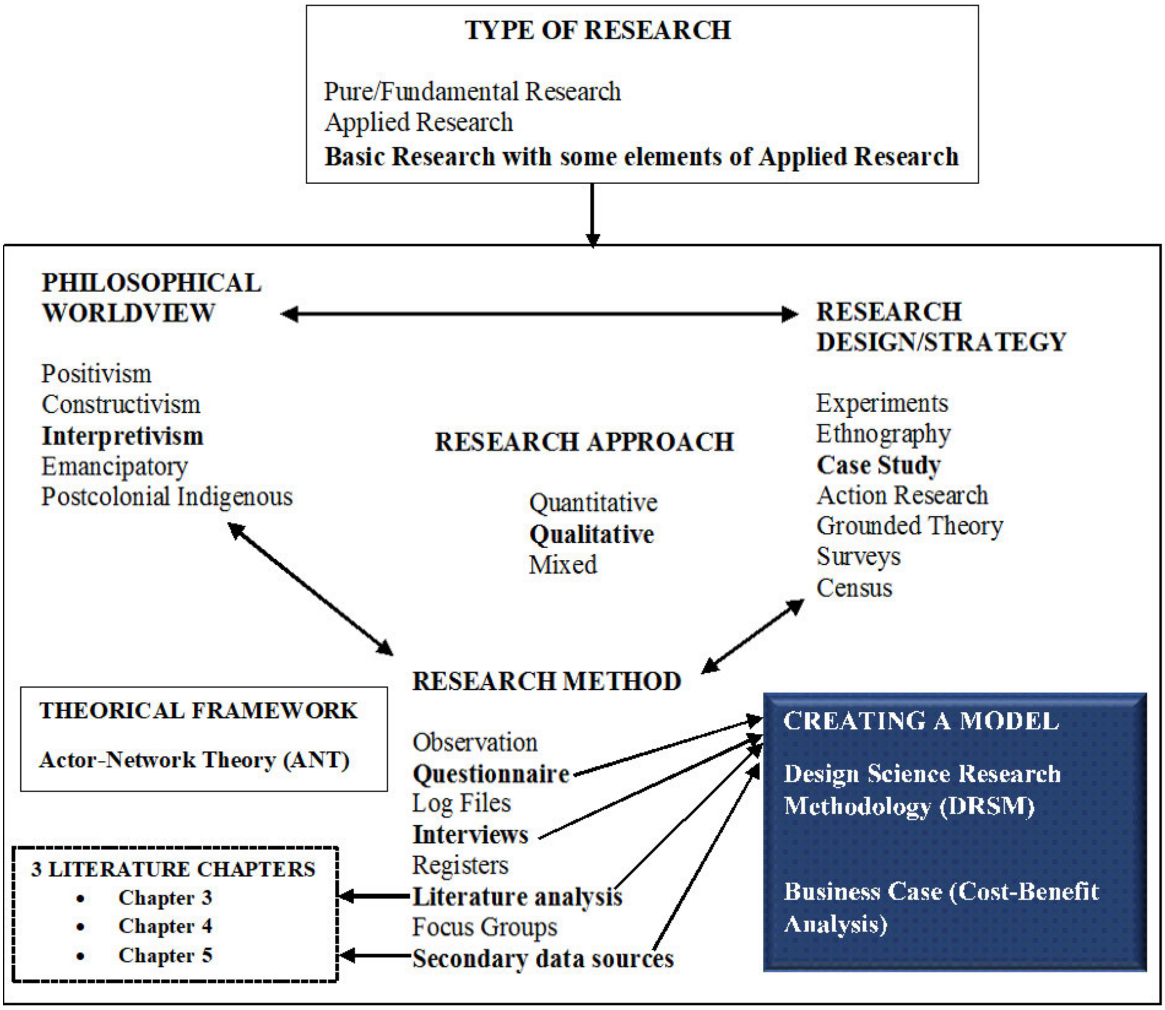


Figure 2: A framework for research adopted in the thesis
Source: Author's own illustration based on research methodological decisions

1.8. Contribution of the Study

The contribution of this study is 'four-fold'. The main contribution the study is the pragmatic solution (model) to a practical problem (livestock theft). Secondly, the research study contributes empirical findings from the gathered primary data to the problem of livestock theft. Thirdly, the study provides a business case for the proposed pragmatic solution. Fourthly, the study contributes both a synthesis of the literature and implications for future research.

1.9. Structure of the Thesis

This thesis is organized as follows:

Chapter 1: The chapter presents the context, introduction, background, statement of the problem, aim, and objectives of the study.

Chapter 2: This chapter discusses and justifies the theoretical framework underpinning the study.

Chapter 3: This literature chapter provides context of the South African livestock farming sector. The chapter provides also information on ICT use/adoption in the South African livestock farming sector.

Chapter 4: This literature chapter provides an overview of the various aspects related to livestock theft in South Africa.

Chapter 5: This chapter provides further literature review on livestock identification and tracking in the context of livestock theft across the world.

Chapter 6: This chapter presents the research methodology guiding the study.

Chapters 7: This chapter provides the findings, interpretations and discussions from the gathered and analysed data.

Chapter 8: This chapter develops the conceptual model of a livestock identification and tracking system for controlling livestock theft in South Africa.

Chapter 9: This chapter revisits the research and highlights the key contributions of the study. The delimitations and limitations of the study are also stated and suggestions for future research are proposed in this chapter.

1.10. Summary of Chapter One

In South Africa, livestock theft is a national problem that affects all farmers. Identification of livestock and tracking of lost, stolen, or otherwise missing livestock remains a challenge in South Africa. Several research studies and various institutions have called for the utilization of ICTs to deal with the problem of livestock theft. Research on exploring the role of ICTs among the South African livestock stakeholders (farmer, government, communities, traditional authorities and industry organisations) to control livestock theft is still limited. Hence, this study aims at exploring how livestock stakeholders can utilise ICTs to deal with (address) livestock theft in South Africa. The goal of the research study is to propose a model of a livestock identification and tracking system for controlling livestock theft in South Africa.

The chapter provided the background of the research study and introduced the research problem. This chapter has highlighted the importance of 'why' the research on livestock theft, livestock identification, tracking and ICTs is needed. The chapter outlined the research objectives and research questions to be used to achieve the outlined aims and goals. Finally, the chapter provided an overview of the structure of the thesis. The next chapter provides the theoretical framework underpinning the research study.

CHAPTER 2

THEORETICAL FRAMEWORK

2.1. Introduction

A theoretical framework is one of the most important aspects in the research process of a thesis/dissertation (George and Vinz, 2022). This chapter addresses six basic questions: (i) "what is a theoretical framework?", (ii) why is a theoretical framework necessary for the research study?", (iii) "what purpose does a theoretical framework serve?", (iv) "which theory was used in the research study to support the theoretical framework?", (v) "why the particular theory was chosen?", and (vi) "how the particular theory was applied?".

A theoretical framework is the researcher's lens with which to explain or investigate a phenomenon, draw connections, make predictions, or view the world' (George and Vinz, 2022; Kivunja, 2018). It provides a grounding base and serves as the structure and support for the rationale for the study, problem statement, aim, significance, research questions/objectives, methods, and analysis (George and Vinz, 2022). According to George and Vinz (2022), the inclusion of a theoretical framework in a research study can serve any of the following purposes:

- Test whether a theory holds in a specific, previously unexamined context.
- Use an existing theory as a guide to assist in determining which aspects will be measured, examined/evaluated or explored.
- Use an existing theory to support the data, interpret the findings/results, and underlie the recommendations.
- Critique or challenge a theory.
- Combine different theories in a new or unique way.

In this study, the researcher uses an existing theory as a basis for supporting the data, and interpreting the findings (George and Vinz, 2022; Kivunja, 2018). The existing theory is used as a guide to assist in determining which aspects will be examined/evaluated or explored (George and Vinz, 2022). These will be done after various relevant Information Systems (IS) theories have been evaluated. The researcher will then select and justify the suitable and applicable theory underpinning the study.

2.2. Relevant Information Systems Theories

The aim of the research study is to explore how livestock stakeholders can utilise/use ICTs to control livestock theft in South Africa. The goal is to develop an information systems model of a livestock identification and tracking system to control livestock theft. An information system is composed of people, business rules, procedures, database, hardware, software, network, etc. In its nature, Information Systems is a multidisciplinary area of study and practice that focuses on the design, development, management, and adoption and use of ICTs, IT and information systems. That is why there are many multidisciplinary-based theories widely used in IS research.

To determine the inclusion of relevant or applicable IS theories in this chapter, the various criteria were established. The established criteria guided the selection and evaluation of theories to ensure they align with the research aim, objectives and methods, and the unique context of livestock theft control in South Africa. The established criteria are described below.

- **Relevance to ICT utilization in livestock theft control:** The theory should be directly applicable to the use of ICTs in controlling livestock theft. This includes considerations for the adoption, use, and effectiveness of ICTs in a multifaceted environment involving various stakeholders such as farmers, government agencies, and law enforcement.
- **Multi-stakeholder focus:** Given the national scope of livestock theft, the theory should be capable of addressing a range of actors and their interactions. This includes not only individual technology users but also organizations and groups that play a role in livestock management and theft prevention.
- **Socio-technical factors and interconnectedness:** The selected theory should be adept at analysing complex networks and the interplay between human and non-human actors. This is essential for understanding the comprehensive system needed for livestock identification and tracking, which involves technology, people, animals, and institutional factors. The theory should offer a holistic perspective, integrating both social and technical elements. This includes understanding the technological infrastructure, animal welfare concerns, cultural considerations, and ethical dimensions related to livestock theft and its control.
- **Alignment with research approach:** Since the study employs a qualitative approach, the theory should support qualitative research methods. This includes facilitating the

exploration of relationships, processes, and contextual factors that influence the ICT implementations in livestock theft control.

- **Alignment with research paradigm:** The theory should align with the overall research paradigm and methodology of the study. This ensures coherence between the theoretical framework and the research design, facilitating effective data collection and analysis.
- **Interdisciplinary integration:** The theory should facilitate the integration of insights from various perspectives. This ensures a comprehensive approach to addressing the research problem.

The relevant multidisciplinary-based theories widely used in IS research are described below. While describing them, each theory is evaluated and a decision is made whether a particular theory is applicable or not for this current study.

2.2.1. Technology Acceptance Model and Unified Theory of Acceptance and Use of Technology

I describe these two models together in this sub-section, because they are similar and related. The key variables of the Technology Acceptance Model (TAM) include Perceived Ease of Use, Perceived Usefulness, Behavioural Intention to Use, and Actual System Use. The TAM suggests that these variables are the key determinants of technology adoption (Marangunić & Granić, 2015). The TAM is relevant to the context of ICTs, IT or IS for livestock theft; particularly when considering the adoption and use of ICTs to address livestock theft, or in the context of livestock identification and tracking system. For instance, Alamgir (2012) used TAM to research radio frequency identification (RFID) technology in the context of animal tracking system in Australia.

The Unified Theory of Acceptance and Use of Technology (UTAUT) is an extension of the TAM because it essentially included two of the model's variables; i.e. Perceived Usefulness became Performance Expectancy and Perceived Ease of Use became Effort Expectancy. The additional variables of UTAUT included Social Influence and Facilitating Conditions. The UTAUT model condensed thirty-two (32) variables found in the eight prominent technology acceptance model (Marikyan & Papagiannidis, 2021). Similarly, the UTAUT seeks to explain and predict technology acceptance and use by individuals or organizations (Marikyan & Papagiannidis, 2021). The UTAUT is relevant to the context of

ICTs, IT or IS for livestock theft; particularly when considering the adoption and use of ICTs to address livestock theft.

The main issue with TAM and UTAUT for the current study is that they primary focus on individual technology-user acceptance than diverse stakeholder groups. Addressing or controlling livestock on a national level would encamps a diverse stakeholder groups including farmers, government, law enforcement bodies, etc. Another issue with the two models is that they do not consider the network, alliance of networks, and animal welfare. Furthermore, the two models are mostly applicable for quantitative research studies. The current study is qualitative in approach. Therefore, in the context of the current study, TAM and UTAUT are not applicable for the current study, despite them being relevant for ICT use/adoption and livestock theft.

2.2.2. Diffusion of Innovations Theory

The Diffusion of Innovations (DOI) theory focuses on the process by which technological innovations are communicated and adopted within a social system over time. The DOI has four main elements, namely: innovation, communication channels, time, and social system (Rogers et al., 2014). The theory is relevant to the context of ICTs, IT or IS for livestock theft; particularly when analysing the spread and adoption of innovative ICT/IT/IS solutions in livestock theft control or livestock identification and tracking system. For instance, Sharma et al. (2007) used DOI to research strategic and institutional perspectives in the adoption and early integration of RFID technology in the context of livestock identification and tracking. Similarly, Hossain & Quaddus (2010) conducted a study on the adoption diffusion model of RFID-based livestock management system in Australia.

The DOI application does not directly align with the current study. This is because DOI primarily focuses on the process of technological innovation adoption. The theory does not address issues like technological infrastructure, animal welfare, unique challenges and dynamics of livestock theft, ethical dimensions, and cultural considerations. A theory that considers the multifaceted nature of the livestock theft problem in the country would be more appropriate for this current study.

2.2.3. Task-Technology Fit Theory

The Task-Technology Fit Theory (TTF) seeks to explain the utilisation of technology by examining the fit of technology to users' tasks/requirements. The theory primarily relates to specific tasks in organizational contexts (Furneaux, 2012). A national livestock identification and tracking system encompasses a broader set of multi-stakeholder and functions, beyond a specific or particular organisational setting. In the context of livestock theft or livestock identification and tracking system, there are no research studies that applied TTF were found in the literature. A theory that addresses the multi-dimensional nature of the livestock theft problem in the country would be appropriate for this current study.

2.2.3. Actor-Network Theory

The Actor-Network Theory (ANT) is a socio-technical framework that examines the interactions and relationships between both human and non-human entities within networks. This socio-technical systems theory views technology, people, livestock, objects, and other elements as "actors" and emphasizes the role they play in shaping social and technological phenomena (Crawford, 2020; Alexander & Silvis, 2014). For example, in the case of livestock identification and tracking system, the control of livestock theft (societal order) would break down if farmers or governments were to be excluded from the system. The ANT is relevant when seeking ICT/IT/IS solutions for controlling livestock theft. The theory is useful for exploring and analysing the network of actors, including livestock, technology, and human agents, involved in the livestock identification and tracking system.

The ANT can be applied to understand the social connections and relationships among livestock theft ‘fighters’ and their associates. The theory can also be applied to understand the social connections and relationships among livestock thieves and their associates. Identifying key actors, their connections, relationships and networks is important for addressing and controlling livestock theft. When applying ANT to the problem of livestock theft in South Africa, it can provide a unique perspective on how various actors and factors can come into play.

2.3. The Applicable and Adopted IS Theory: Actor-Network Theory

This study adopts ANT as a theoretical framework to address the phenomena of interest, using an IS perspective. The next sections focus on ANT. The sub-sections of this section provide a brief background of ANT, a detailed justification for adopting ANT, conceptualisation and contextualisation of ANT for the current study, and the mapping of ANT variables to the various elements of the current study.

2.3.1. Brief Background of Actor-Network Theory

The origin of ANT can be traced back to science and technology studies, and sociology of science studies (Muller, 2017; Latour, 2007). The theory was originally developed by two science and technology scholars Bruno Latour and Michel Collen, and the sociologists John Law in the 1980s. According to Latour (2007, P.141), the main argument of ANT is that

> "The world is made up of actors in alliances with other actors that are physical, social, subjective, objective, fictional or real. The ANT is based on the concept of heterogeneous network – a coextensive network containing dissimilar elements".

Latour (2007) further proposes that the interconnectedness of actors is not enough; what is important is the sort of actions flowing between the actors and the effect that is produced.

The ANT distinguished from other theories used in IS research in that an actor-network contains not just people and technology, but non-humans (e.g. animals, livestock, etc), objects, and materials (Latour, 2007). In an actor-network, people, non-humans, objects, technology, and organizations are collectively referred to as actors, or actants. In an Actor-Network, each element (actant/actor) of the system whether natural, non-human, technological, or human has an equal part to play in the system, and must be considered. Every situation that occurs is referred to as a network – a network is a group of actants/actors that interconnect/interact and affect each other. Societal order is an effect caused by an actor-network running smoothly; and the societal order begins to break down when certain actors are removed. Figure 3 below illustrates a summary of ANT.

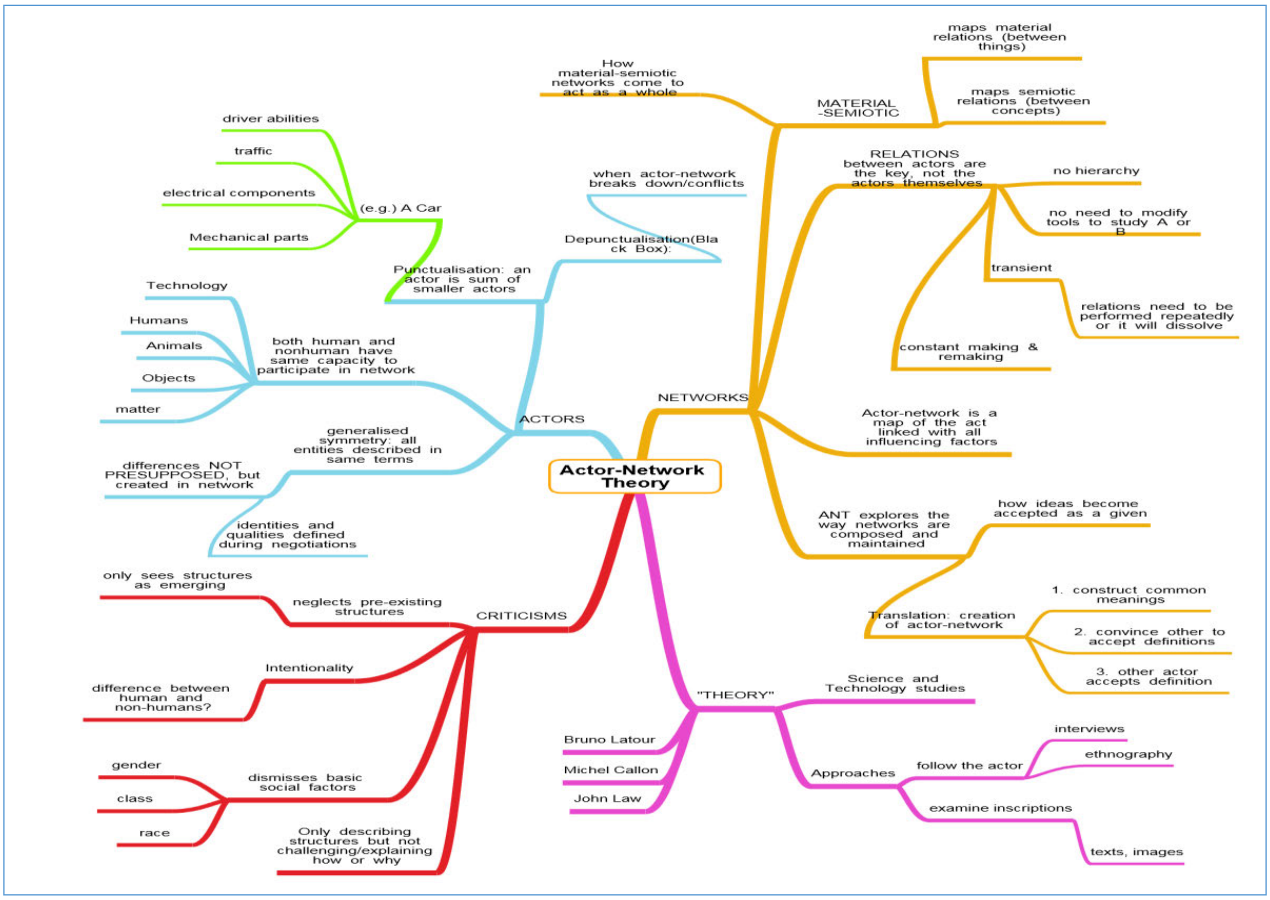


Figure 3: Summary of Actor-Network Theory
Source: Delukie (2019); Ryder (2014)

2.3.2. Justification for the Use of Actor-Network Theory and its Key Concepts

There are eight aspects that make the use of ANT applicable for the current study, namely: animal welfare issues; complex network of actors (humans); non-human actants (technology and livestock); actor-network; diverse perspectives and interactions; translational processes; institutional and socio-economic factors; and qualitative methods. The justification for the use of ANT is based on these mentioned eight aspects.

According to Animal Welfare Guiding Principles, the identification and tracking of livestock should be done in accordance animal welfare issues (WOAH, 2018). Unlike most IS based theories, ANT supports the treating of non-humans and humans in the same way – all elements whether human, non-human or technical in a system are treated as equally important (Law, 1992). From a socio-technical perspective, ANT provides a mechanism for developing a holistic IS-based system with examination of all components be they natural, non-human, technological, or human (Muller, 2017; Doolin & Lowe, 2002). The welfare issue is one of the strengths of the ANT in context of this study.

Controlling livestock theft with the use of ICTs is a complex phenomenon that would involve many elements such as farmers, government and law enforcement agencies, traditional authority, communities, technology, animals, technology providers, etc.). The ANT is well-suited for analysing the interactions among these elements; and this is supported by Delukie (2019), (Muller, 2017), Ryder (2014), Latour (2007), and Doolin & Lowe (2002). Most of the theories used in IS research tend to focus more on the technological elements, with little or no attention to the non-technological elements. The ANT recognises the interaction among humans, non-human/non-technological things (for example, animals) and technology (Latour, 2007). The socio-technical nature of ANT fits well in the research study, because a livestock identification and tracking system would require an integration of multiple elements including people, livestock, and technologies.

The actor-network is one of the important concepts of ANT. The concept explains heterogeneous network of aligned interests, including people, organizations, ICTs, and standards to satisfy their diverse aims (Walsham, 1997). For an example, an ICT-based livestock theft reporting forum that involves the use of computers, mobile phones by the human actors such as farming communities. In this case, animals (livestock) would be part of the actor-network.

The ANT accommodates diverse perspectives and interests of various actors (Cresswell et al., 2010). This argument is supported by Plesner (2009), and Lind (2003). For example, in the context of South Africa, different stakeholders may have varying needs and expectations from the livestock identification and tracking system for controlling livestock theft. The ANT can help explore, analyse and understand these differences. This aspect is one of the strengths of the ANT in context of this study.

One of the most important strengths of the ANT is that the theory focuses on the translation of technology and practices into the actor-network (Muller, 2017). The ANT translation explains how actors, actants and intermediaries come together, interact to form an actor-network (Walsham, 1997). The concept of ANT translation is relevant for understanding how the livestock identification and tracking system would integrate various actors, actants and intermediaries.

Exploring and analysing the antecedents related to institutional and socio-economic factors (e.g. cultural practices, technology costs, technology, technology accessibility, technology availability, etc) in the country is important in this study. The ANT offers the exploration and analysis of the antecedents related to institutional and socio-economic factors. This argument is supported by Aka (2019), Muller (2017), and Dolwick (2009).

This study is interpretive in paradigm, and qualitative in approach. In the context of Actor-Network Theory (ANT), qualitative research methods are often used to explore, analyse and understand the intricate relationships, processes, and antecedents that shape actor-networks (Justesen, 2020). The current research is case study-based, focusing on South Africa context. This research design aligns with ANT, because according to Crawford (2020) the ANT resists large generalizations. In a case study, qualitative methods such as interviews, observations, systematic literature reviews, thematic analysis, and content analysis can be used to map the interactions among actors and actants, and how they influence one another (Justesen, 2020; Crawford, 2020).

It is for these for this justification that the ANT is best suited as the theoretical lens to address the research problem of this study as well as the research aim, goal, questions and objectives. Through ANT, the researcher is able to analyse the assemblage and roles of the human actors as well as that of the non-human actors in controlling livestock theft in the country.

2.3.3. Contextualisation and Conceptualisation of the Actor-Network Theory

A livestock identification and tracking system could be depicted as a three-dimensional system: social system (people and organisations/institutions), technical system (hardware, databases, software, algorithms, procedures, and networks), and other system (animals or livestock). According to ANT, people, animals, and technology would be viewed as actors/actants in a livestock identification and tracking system. Each of the actors would have some effect on one other: for example, the technology would impact the rate of recovery of stolen livestock. Figure 4 below depicts contextualisation and conceptualisation of the Actor-Network Theory in alignment with the problem, research questions and objectives, methods and goal of the research study.

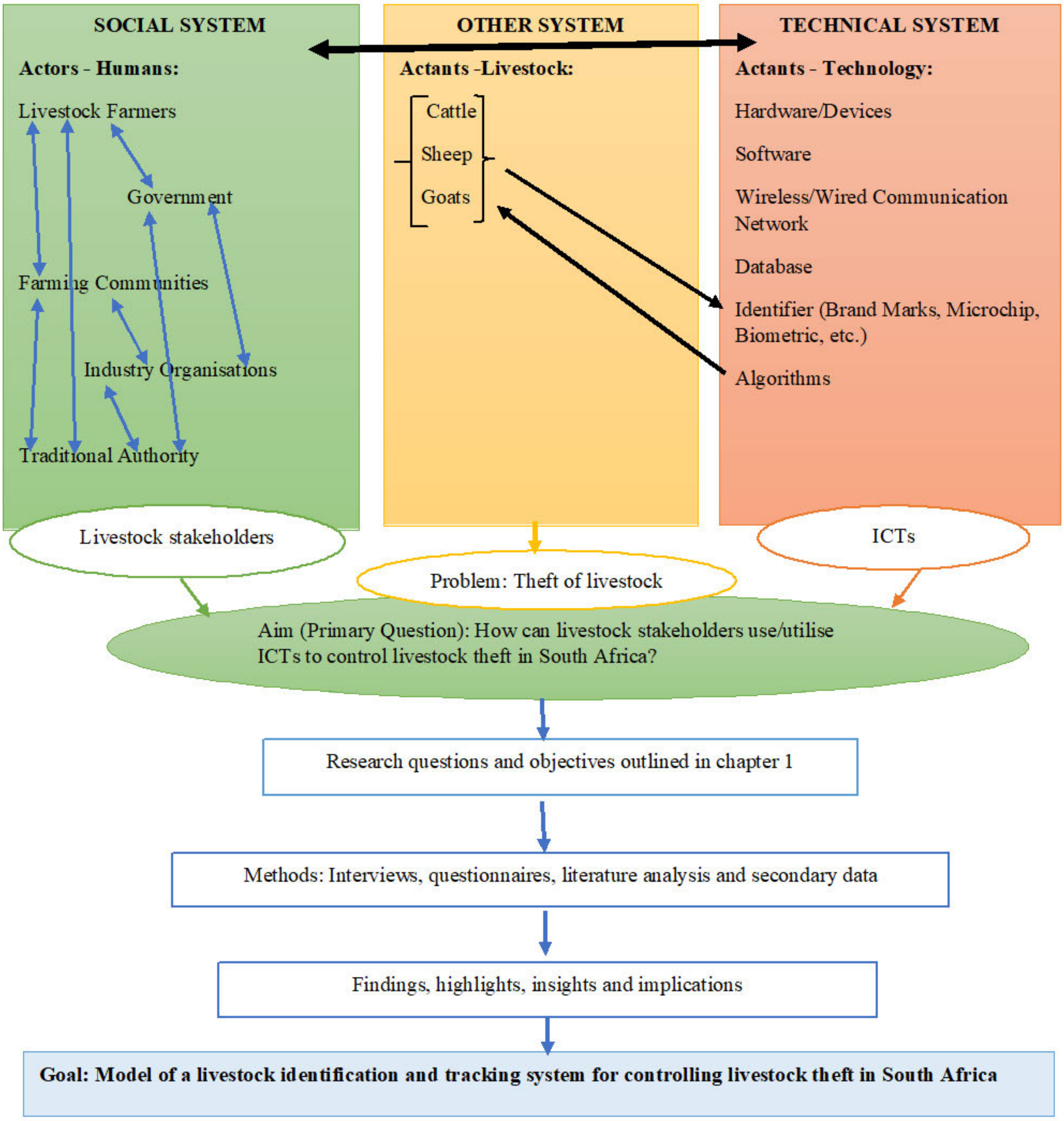


Figure 4: Conceptualisation of Actor-Network Theory in the context of a livestock identification and tracking system.
Source: Author`s own illustration

2.3.4. Mapping of ANT Variables to the Relevant Research Questions, Method of Data Collection and Method of Data Analysis

In section 2.1 of this chapter, it was stated that a theoretical framework provides the structure and support for the rationale for the study, problem statement, aim, significance, research questions/objectives, methods, and analysis. In this study, the ANT offers theoretical (socio-technical analysis) and methodological (socio-technical graph) tools to examine research questions. It is for this purpose that a summary of the mapping of ANT variables to the relevant research questions, method of data collection and method of data analysis is provided in this section. This mapping creates a structured framework that links specific elements of the study, which helps create a clear plan for conducting the study. This is shown in table 1 below.

As show in table 1 below, the identified key ANT variables are actors, actants, intermediaries, translation, and network. These variables represent the key components involved of the current study. Actors refer to the human and non-human entities. This can include farmers, law enforcement officers, livestock, technologies, and local communities. Actants refer to objects or technologies. Intermediaries refer to the mechanisms or factors influencing the interactions among actors and actants. This can involve factors like socioeconomic conditions, practices, and the availability of technological resources. Translation refers to the process of interaction and negotiation among actors and actants. The aim of translation is to understand how actors and actants can come together to create the conditions for a livestock identification and tracking system in order to control livestock theft in the country. Network refers to the overall information system structure of connections and relationships. By applying ANT, the researcher is able to interrogate shared and different interests among actors/actants together with the resultant interaction to discover an evidence-based of a livestock identification and tracking system which is elaborated upon in Chapter Eight.

Table 1: Mapping of Actor-Network Theory variables to the specific elements of the study

Theory variables	Research question	Method of data collection	Method of data analysis	Links to chapter
Actors. Actants. Intermediaries. Translation. Network.	Research Question 1: How does livestock theft occur in South Africa?	Secondary data, Literature, and Interviews.	Qualitative Data Analysis: Content analysis and thematic analysis.	Chapter 4 and Chapter 7.
	Research Question 2: Who are the important actors involved in the fight against livestock theft in South Africa?	Secondary data, Literature, and Interviews.	Qualitative Data Analysis: Content analysis and thematic analysis.	Chapter 4, Chapter 5 and Chapter 7.
	Research Question 3: How can the important actors be organized to control livestock theft in South Africa?	Secondary data, Literature, and Interviews.	Qualitative Data Analysis: Content analysis and thematic analysis.	Chapter 3, Chapter 4, Chapter 5 and Chapter 7.
	Research Question 4: What is the nature of use of livestock identification methods and tracking methods by the human actors for controlling, mitigating, or combating livestock theft in South Africa?	Secondary data, Literature, and Interviews.	Qualitative Data Analysis: Content analysis and thematic analysis.	Chapter 3, Chapter 4, Chapter 5 and Chapter 7.
	Research Question 5: What are the suitable, available, and effective ICTs that can be used for livestock identification and tracking in order to control livestock theft in South Africa?	Secondary data, Literature, and Interviews, Questionnaires.	Qualitative Data Analysis: Content analysis and thematic analysis.	Chapter 3, Chapter 4, Chapter 5 and Chapter 7.
	Research Question 6: What are the information system components required to develop a holistic and national livestock identification and tracking system for controlling livestock theft in South Africa?	Secondary data, Literature, and Interviews, Questionnaires.	Qualitative Data Analysis: Content analysis and thematic analysis.	Chapter 3, Chapter 4, Chapter 5 and Chapter 7.

Source: Author`s own illustration based on ANT variables and study`s research questions

2.4. Summary of Chapter Two

This study is conducted from an Information Systems perspective. In this chapter, the researcher identified and described various IS theories, to select the most suitable theory for the research study. From the various theories used in IS research, ANT was chosen as the suitable and applicable theory guiding the research study. Justification for choosing ANT was provided in this chapter. The conceptualisation of ANT in the context of livestock identification and tracking for controlling livestock theft was outlined. An alignment of the conceptualised ANT with the research study`s problem, aim, research questions and objectives, methods and goal were provided.

The next chapter deals with the literature on the South African livestock farming sector. The chapter presents an overview of various aspects related to the livestock farming sector that include livestock stakeholders, and ICTs.

CHAPTER 3

LITERATURE REVIEW: SOUTH AFRICAN LIVESTOCK FARMING SECTOR

3.1. Introduction

As already stated in chapter one, this thesis consists of three literature review chapters. This is the first of the three literature review chapters. The chapter synthesises and summarises the context and characteristics of the livestock farming sector in South Africa. The ICT use/adoption in the South African livestock farming sector are synthesised and summarised in this chapter. The chapter seeks to address the research objectives/questions outlined in Chapter One. For instance, one of the research objectives/questions relates to determining the ICTs that have been adopted by actors involved in the combat against livestock theft in South Africa. Another research objective/question is to explore the suitable, available and effective ICTs that can be utilised for livestock identification and tracking to control livestock theft in South Africa. For this purpose, the chapter identifies and assesses the information system components and features for inclusion in a model for a livestock identification and tracking system suitable for controlling livestock in the South African context.

3.2. Information Gathering and Analysis Method

The chapter uses the publicly available information from journal articles, news websites, reports, magazines, books, conference papers, etc. The inclusion criteria and exclusion criteria were applied based publication dates, language, and geographic relevance. The inclusion of sources was based on the aspects of relevance and up-to-date information (published between 2010 and 2023). This was assessed by reading the summary of each article, report, paper, thesis, and dissertation. This chapter only used information that is written in the English language. Articles, reports, papers, thesis and dissertations that met the predefined criteria were utilised. The chapter primarily focuses on South African context. To analyse (i.e. synthesise and summarise) the gathered information, a combination of five approaches were applied, namely: descriptive/narrative form, categories, exploratory approach (finding connections in the information), tables and graphs.

3.3. Context and Characteristics of the Livestock Farming Sector in South Africa

The Department of Agriculture, Land Reform and Rural Development (DALRRD) is mandated to oversee the livestock sub-sector activities of the agricultural sector in South Africa. The activities include developing value chains and policies; providing inputs; monitoring production and consumption; advising, empowering and supporting farmers; and facilitating comprehensive rural development in the livestock sub-sector. To implement the mandate, the Department has two branches that are specifically dedicated to livestock, namely: animal health, and animal production. The different livestock roles such as extension officers, animal production specialists, animal health technicians, general technicians, veterinarians, and animal scientists exist within these two branches. For instance, the extension officers act as a bridge between farmers and various stakeholders such as government, researchers, scientists and technologists. They disseminate information to farmers, educate and advise farmers on sustainable agricultural practices (DALRRD, 2022).

South Africa is characterized by a dualistic livestock sector. There are two broad categories of livestock farmers in the country, namely: communal farmers and commercial farmers. The communal category is generally composed of subsistence and smallholder farmers, while the commercial category is generally composed of large-scale farmers and emerging farmers. There are some other distinctions between commercial livestock farming and communal livestock farming in the country. One distinctive characteristic is that there are more livestock farmers in the communal sector than in the commercial sector (Stats SA, 2020; StatsSA, 2018). In terms of cattle and goats holding, the communal livestock farming sector has a higher share than the commercial livestock farming sector. The communal sector is largely concentrated in the rural areas. In terms of infrastructure, technology and financing, the commercial livestock farming sector is well developed and capital-intensive, unlike the communal livestock farming sector. For instance, in the commercial livestock farming sector, the movement of livestock is controlled with fenced farms, while in the communal sector grazing areas tend to be shared by members of the community with no controlled demarcations. In the communal livestock farming sector, the objectives of livestock ownership are not just for economic needs but also for socio-cultural needs such as traditional rituals, ceremonies and customs (FAO, 2020; Clack, 2013). Table 2 below shows some characteristic differences between the commercial livestock farming sector and communal livestock farming sector in South Africa.

Table 2: Characteristic differences between the commercial livestock farming and communal livestock farming in South Africa

ASPECTS	COMMUNAL LIVESTOCK FARMING SECTOR	COMMERCIAL LIVESTOCK FARMING SECTOR
Nature/Setting	Largely informal.	Formal.
Economic orientation	Multiple use/multi-purpose (e.g. socio-culture, manure, subsistence, capital, etc.).	Profit (commercial).
Income	Low levels of income.	Relatively high levels of income.
Education	Low levels of education.	Relatively high levels of education.
Human population density	Densely populated.	Less densely populated.
Livestock	Mixed farming: cattle, sheep, goats, pigs, chicken, etc.	Mainly cattle and sheep.
Maintenance of natural resources	Poor.	Economics and strong peer pressure to achieve desired conservation state
Livestock owners (population).	Many farmers – in 2010, it was estimated that there were about 2 million communal farmers in South Africa.	A few thousand farmers – the 2017 census on commercial farmers indicates that there about 40 122 commercial farmers in South Africa.
Infrastructure	Poor.	Relatively good (road system, power network, fencing and water provision)
Access to formal markets	Poor.	Good.
Access to subsidies and loans	Weak.	Good.
Land use	Mainly previously homelands.	46,4 million hectares, which represents 37,9% of the total land area of South Africa (122,5 million hectares), of which (36,5 million hectares) is mainly grazing land for livestock and game.
Grazing land	Shared by communities – no demarcations.	Fenced ranches.
Government support	Poor.	Relatively good
Access to ICT	Mainly Radio, TV, Mobile Phones.	Computers, Radio, TV, Mobile Phones, Internet.

Authors illustration based on World Bank Group (2023); StatsSA (2020); FAO (2020); StatsSA (2018); WWF (2015)

3.4. The Use/Adoption of ICTs in the Livestock Sector

Utilizing ICTs to identify and track livestock would require ICT adoption and use by the country`s livestock stakeholders. This section provides information on the use or adoption of ICTs in the South African livestock farming sector. The ICTs found in the literature include:

- Mobile Devices and Mobile-enabled Products and Services
- Radio and Television;
- Computers and databases;
- Crowd-farming system;
- Bluetooth-enabled camera and digital pen technology; and
- Social media and instant messaging;

3.4.1. Mobile Devices and Mobile-enabled Products and Services

In their empirical study on the use of mobile technologies amongst South African commercial farmers, Simpson and Calitz (2015) found that the majority of livestock farmers use their smartphones to access the Internet. In the same study, livestock farmers indicate that they use their smartphones for e-mail, news and information, weather updates, banking and finance, gaming, entertainment, social media, mobile apps and call/SMS. The study further determined that livestock farmers have adopted tablet wireless devices primarily for business purposes. Farmers report the use of these devices for e-mail, banking and information access. In their empirical research study on ICT use by South African livestock farmers, Mdoda & Mdiya (2022) found similar patterns. Similarly, in their empirical research study on the use of ICTs by farmers. Smidt and Jokonya (2022) found similar patterns.

Uys (2017) provides a summary of useful mobile apps for herd management in South Africa. The design of the HerdWatch app enables farmers to manage the full breeding cycle and keep track of heat checks, inseminations and gestation scanning. In 2017, it was estimated that there were about 5000 famers using the HerdWatch app. The Moocall Calving Sensor is another mobile app. It is designed to accurately predict when a cow is most likely to give birth by measuring tail movement patterns triggered by labour contractions. The purpose and functionality of the app known as Cow Call calving monitor is similar to the Moocall Calving Sensor and App. Yet another app is MooMonitor+ wireless sensor app. This app allows a farmer to detect individual cows coming on heat and potential health problems. These apps are expensive for communal farmers. For instance, the price of the Moocall Calving Sensor and App with its sensor package is about R4 700, while the price of MooMonitor+ Wireless Sensor app with its sensor package is R53 000. These mobile apps are targeted mostly at large-scale commercial farmers.

There are some noticeable trends in mobile-enabled products and services in the livestock farming sector in South Africa. The mobile-enabled products and services include Formbook mobile app, ARC Hup mobile app, Connected Farmer mobile app, Snap Animal App, Farm Ranger App, and *134*4536# Unstructured Supplementary Service Data (USSD) code. The farmbook mobile app has been developed for commercial farmers and communal farmers. In 2018, the app had about 10 000 users, of which 5 000 were commercial farmers and about 400 were small-scale farmers. The app provides farming advice and information on crops and livestock The ARC mobile app has been developed for all farmers in South Africa. There are two major features of the ARC mobile app. First, identification location of farmers and users via GPS coordinates followed by linking them to a specific advisor in their area to assist with specific crops or livestock information/advice. Secondly, farmers can use the app to alert the authorities with regard to the emergence of a specific pest (Government of South Africa, 2021; Luthuli, 201; ARC. 2014). The USSD automated code *134*4536# is a government initiative that is mainly targeted for communal farmers, small-scale and sustenance farmers to apply for a government subsidy-voucher. The USSD automated code is accessible through any mobile phone, irrespective of the mobile network (Government of South Africa, 2021).

In 2017, Vodacom (a South African Telecommunications Company) announced that it would develop a mobile app called Connected Farmer for the South African farmers. Vodacom announced that the Connected Farmer mobile app would be a cloud-based web and mobile software solution that will link thousands of smallholder farmers to the agriculture value chain enabling access to information, services, and markets (Lourie, 2017).

3.4.2. Radio and Television Broadcasting

An empirical study conducted by Mdoda & Mdiya. (2022) found that radios and televisions are some of the most frequently used and utilised ICTs by livestock farmers in the country. Livestock farmers reported that they were using radios and televisions to listen to market information and new agricultural inputs through radio adverts as well as announcements from agricultural officials. They conclude that radio and television are very crucial sources of agricultural information and communication technologies that assist the majority of the farmers with current information and agricultural techniques. In a similar study, Smidt (2022) found that livestock farmers were using radios and televisions. AgriTV, Living Land, Landbousake, Ons Boere, Ons Inspirasie, Landbouweekliks, Plaaspraatjies, Nation in Conversation, Radio Sonder Grense, Radio Elsenburg, Radio Pretoria, Grain SA, Landbou Radio, and the KwaZulu-Natal Department of Agriculture and Rural Development are some of the broadcasting programmes focusing on agricultural issues in South Africa (Agribook, 2020).

3.5.3. Computers and Databases

In an empirical study on ICT use by South African commercial livestock farmers commercial reported that they use computers and databases to disseminate information quickly and fast (Mdoda & Mdiya, 2022). The livestock commercial farmers reported that they use computers and databases for keeping records. Smidt and Jokonya (2022) found similar patterns.

3.4.4. Crowd-farming System

Crowd-farming is an alternative to traditional agricultural investment. The crowd-farming system refers to a platform that gives users/investors ownership over the land, livestock, and cultivated crop by a remote farmer. Livestock Wealth is a South African based company that offers crowd-farming through its mobile application, website and desktop application. Interested individuals and companies can invest in livestock such as pregnant cows, calves and free-range oxen. The company claims that through its electronic crowd farming system, it has attracted more than 3000 investors and more than 70 partners have been impacted (Livestock Wealth, 2022).

3.4.5. Bluetooth, GPS, Camera and Digital Pen Technology

The DALRRD in partnership with the Xcallibre Technology Company implemented a farm-monitoring project. In this project, the DALRRD`s extension officers use Bluetooth-GPS/camera equipped mobile phones to capture and record farm visits into a centralized database. The Bluetooth-GPS/camera equipped mobile phones are complemented by a digital pen technology for taking notes, and recording both the notes and the farms` GPS coordinates into a centralized database. Reports indicate that the extension officers have accepted the project and have therefore adopted the camera-enabled mobile phones for farm visits. The project, through the use of mobile phones have provided many benefits to the DALRRD. These include (i) properly tracking field staff and ensuring that the correct sites are visited and reported on each month; (ii) spatially mapping of all farm visits; and (iii) providing visual representation of farm visits by attaching photos (Xcallibre, 2016).

3.4.6. Social Media and Instant Messaging

Red Meat Organisation (2015) reported the use of social media by livestock farmers in collaboration with the Gauteng Stock Theft Prevention Forum. The Forum created the Statistieke (VAS) (Livestock Theft Reporting and Statistics) group on Facebook in 2013. The Facebook group allows farmers and other role players in the red meat industry to post livestock theft cases. The main aim of the Facebook group was to create public awareness and share intelligence about livestock theft where possible. Boucher (2018) provides information about instant messaging from an affected and concerned livestock farmer. The concerned farmer in that article stated:

> "Livestock theft is rife in the Newcastle and Normandien areas of Kwazulu-Natal province. There is a WhatsApp group for farmers in the area and not a week goes past, without someone posting to be on the lookout for stolen animals."

The SAPS has a Facebook page and Twitter page. These pages are generic, and the information posted on the pages include daily/weekly news and updates about crime related matters (SAPS, 2022). According to crime reports published by SAPS, livestock theft is one of the serious crimes in the country. The South African rural safety strategy has listed livestock theft as one of the priority rural crimes that needs to be addressed in the country.

3.4.7. Internet of Things

IoT.nxt (2022) provides a livestock tracking case and testimonial from a South African livestock commercial farmer in Pretoria. The farmer`s cattle are fitted with solar panel powered IoT tags. The tags send data to a central point which can be viewed using mobile phones or computers. To send data to a central point, the IoT based system relies on a tower installed on the farm.

3.5. Addressing the Research Questions

In section 3.1, it was stated that this chapter seeks to address some of the research questions posed in Chapter One. The findings obtained in this chapter provide valuable insights into the various ANT actors, actants, intermediaries, translation processes, and annetworks required to develop a holistic and national livestock identification and tracking system for controlling livestock theft in country. Table 3 below provides a summary on how this chapter has addressed some of study`s research questions.

Table 3: Addressing the research questions – chapter 3

Research question	**Key Findings in relation to theory variables**
Research Question 3: How can the important actors be organized to control livestock theft in South Africa?	• Identified actors: DALRRD`s different livestock roles such as extension officers, animal production specialists, animal health technicians, etc. Subsistence and smallholder farmers, large-scale farmers and emerging farmers. The police (law enforcement agencies). • Identified actants: Internet, Cellular Network, Radio, TV for information dissemination. computers and databases for livestock for keeping livestock records. • Identified intermediaries: Technology providers, e.g. Xcallibre Technology Company. • Identified translation: Technology providers have a link with DALRRD. • Identified networks: A forum of livestock farmers in collaboration with communities via social media.
Research Question 4: What is the nature of use of livestock identification methods and tracking methods by the human actors for controlling, mitigating, or combating livestock theft in South Africa?	• Identified actants: Social Media and Instant Messaging for tracking stolen livestock. Solar panel powered IoT tags and network tower installed on the farm for tracking stolen livestock. GPS technology for tracking livestock. Herd Management Apps. • Identified translation: Local communities have a link with farmers. The farmer has a direct link to livestock via IoT tags. • Identified networks: A forum of Livestock farmers in collaboration with the Stock Theft Prevention Forum. IoT based network.
Research Question 5: Which ICTs have been adopted by the human actors involved 'in the fight against' livestock theft in South Africa?	• Identified actants: Mobile devices, TV, Radio are the most adopted forms of technology. • Mobile-enabled products and services are on the rise. • Social Media and Instant Messaging are being used.
Research Question 6: What are the suitable, available, and effective ICTs that can be used for livestock identification and	• Identified actants: Mobile network, Mobile devices, TV, Radio are the most adopted forms of technology. • Mobile-enabled products and services are on the rise. • Social Media and Instant Messaging are being used.

Research question	Key Findings in relation to theory variables
tracking in order to control livestock theft in South Africa?	
Research Question 8: What are the information system components required to develop a holistic and national livestock identification and tracking system for controlling livestock theft in South Africa?	• Various information system components in the form of actors, actants, translation, and networks exit in the literature, as described above.

Source: Author`s own illustration based on literature review and study`s research questions

3.6. Identified Gaps in the Literature

The findings obtained in this chapter provide valuable insights into information system components required to develop a holistic and national livestock identification and tracking system for controlling livestock theft in South Africa. However, several aspects related to the study`s questions remain inadequately clarified, highlighting the need for further research. There is a lack of research related to some of study`s research questions. The identified gaps in the literature are summarised in table 4 below.

Table 4: Identified gaps in the literature – chapter 3

Research question	Identified gaps
How can the important actors be organized to control livestock theft in South Africa?	There is limited research on the ICT-based strategies and formal/informal structures for coordinating the efforts of various actors to control livestock theft in the country. This study seeks to fill this gap by exploring ways in which stakeholders can utilise ICTs to control livestock theft in the country.
What is the nature of use of livestock identification methods and tracking methods by the human actors for controlling, mitigating, or combating livestock theft in South Africa?	There is limited empirical research on exploring the adoption and practical use of ICT-based livestock tracking methods by various stakeholders in the country. For an example, there is no wide-spread adoption and use of GPS tracker devices among livestock farmers (both commercial and communal) found in the literature for livestock identification and tracking in the country.
Which ICTs have been adopted by the human actors involved 'in the fight against' livestock theft in South Africa?	Literature information is fragmented in this area. A comprehensive empirical evidence on a national scale is lacking in this regard. For an example, there is no wide-spread adoption and use of RFID technology among livestock farmers

Research question	Identified gaps
	(both commercial and communal) found in the literature for livestock identification and tracking in the country.
What are the suitable, available, and effective ICTs that can be used for livestock identification and tracking in order to control livestock theft in South Africa?	The literature reveals that diverse ICTs including emerging technologies are available in the country. However, a holistic and systematically coordinated ICT-based strategy to control livestock theft on a national scale is lacking in this regard. This study seeks to fill this gap.
What are the information system components required to develop a holistic and national livestock identification and tracking system for controlling livestock theft in South Africa?	There is a lack of comprehensive research on the holistic development of a national livestock identification and tracking system to control livestock theft in the country. This study seeks to fill this gap.

Source: Author`s own illustration based on literature review and study`s research questions

3.7. Summary of Chapter Three

Livestock production is one of the most important elements of the South Africa`s rural development, food security, economic growth, heritage and culture, and exports. There are some noticeable ICT trends and developments in the sector. For example, mobile phone technology, radio, television, social media and instant messaging are some of the ICTs adopted by the livestock farming communities in the country. Despite the significant adoption of mobile phone technology, the technology is underutilised in terms of controlling livestock theft in the control. Similarly, despite wide-spread use of radio and TV, there is lack of knowledge management and wide-sharing of knowledge dedicated to livestock theft issues through TV and radio. The country can leverage these adopted ICTs to control livestock theft.

The next chapter focuses on livestock theft in South Africa. The purpose of the next chapter is to gain an in-depth understanding of the various aspects related to livestock theft in the country.

CHAPTER 4

LIVESTOCK THEFT IN SOUTH AFRICA

4.1. Introduction

This is the second of the three literature review chapters. The chapter focuses principally on the most frequently stolen livestock in South Africa, namely cattle, sheep and goats. They are of significant socio-economic and cultural value. To propose a livestock identification and tracking system model for controlling livestock theft, it is worth discussing various aspects related to livestock theft in the country. These aspects include key stakeholders and their interests, scholarly research undertaken on livestock theft, prevalence, dynamics, and scale of livestock theft in South Africa. It is also important to explore the initiatives, programmes, strategies, measures, laws, livestock identification methods, and technologies/systems that have been implemented or adopted to mitigate livestock theft in the country. It is important to identify research gaps, so that the current research study does not repeat the same research undertaken by other scholars, researchers and authors. Therefore, publicly available information from journal articles, news websites, reports, magazines, books and conference papers were used to synthesise and summarise the various aspects related to livestock theft in the country to identify gaps in scholarly literature.

This chapter seeks to address the research objectives/questions outlined in Chapter One. For instance, one of the research objectives/questions is concerned with uncovering how livestock theft occurs in South Africa. Another research objective/question is about reviewing the use of livestock identification and tracking methods employed by livestock stakeholders. Hence, this chapters identifies and assesses the information system components and features necessary for inclusion in the sought-after model. The model is for a livestock identification and tracking system suitable for controlling livestock theft in the South African context.

4.2. Information Gathering and Analysis Method

The SAPS is the major source of livestock theft statistics used in this chapter. The crime statistics from SAPS were used to determine the magnitude of livestock theft in the country and the degree to which livestock stock theft affects the socio-economic standing of South Africa. In addition, relevant government reports, company reports, journal articles, conference papers, theses and dissertations were used as sources of information in this chapter. The criteria for including sources were based on relevant and up-to-date information (i.e. published between 2010 and 2022). This was assessed by first reading the summary of each article, report, paper, thesis, or dissertation. Articles, reports, papers, and dissertations that met the predefined criteria were utilised. This chapter only used information that is written in English language. To analyse, synthesise and summarise the gathered information, a combination of five approaches was used, namely: descriptive/narrative form, categories, exploratory approach (finding connections in the information), tables, and figures.

4.3. Key Stakeholders and Their Interests in Dealing with Livestock Theft

While there has been a steady decrease in other property-related crimes for the past 10 years, livestock theft crimes have been escalating in the country. For instance, the SAPS reported that livestock theft cases increased by 7.2% for the 2017/2018 financial year (SAPS, 2022). The seriousness of livestock theft in the country has necessitated the mobilisation of multidisciplinary stakeholders. These include the DALRRD, SAPS, National Stock Theft Preventative Forum (NSTPF), Provincial Stock Theft Forums (PSTPFs) and farming communities. The multidisciplinary approach of stakeholders arose from the need for a comprehensive and holistic strategy to support the creation of a safe rural environment that combats theft of livestock and other rural crimes (MPO, 2021; Visible Policing, 2019).

In the context of managing livestock theft in the country, the key interest of the DALRRD is to enforce branding and tattooing of all livestock. This is done in cooperation with the SAPS, to prevent livestock theft and control animal disease, as well as to promote animal health (Visible Policing, 2019). The SAPS has specialised STUs throughout the country that deal specifically with livestock thefts (PMG, 2022). The key interests of SAPS' STUs include tracking/tracing of livestock, recovering of stolen livestock, impounding livestock, investigating all crimes related to livestock, and preventing livestock theft (PMG, 2022; Visible Policing, 2019). The established NSTPFs and PSTPFs are constituted by members of SAPS; farmer organisations such as Red Meat Organisation and Red Meat Industry Forum; and interested parties such as livestock farmers (PMG, 2022; MPO, 2021). The forums` key interests are based on preventing livestock theft, providing information on livestock branding, and ensuring legislative compliance (MPO, 2021). Other relevant stakeholders include Community Safety Forums (CPSs), South African National Defence Force (SANDF), Crime Intelligence Department, Department of Cooperative Governance and Traditional Affairs (COGTA), and Houses of Traditional Leaders (Visible Policing, 2019).

4.4. Theoretical Perspectives and South African Research on Livestock Theft

As already stated in the previous chapter, in the context of this research study, livestock refers to cattle, sheep and goats. These are the most targeted farm animals by thieves due to their significant socio-economic and cultural value (SAPS, 2022; Doorewaard, 2020; Maluleke, 2018; Clack, 2015). In South Africa, these domesticated animals are kept, raised, and used by people for economic, cultural, social, religious and political purposes. They are usually kept on a farmstead, or ranch or kraal (Maluleke, 2018). Various countries define livestock theft and categorize livestock theft differently. For instance, in India, livestock theft may refer to cattle raiding, cattle lifting or cattle smuggling; while in Australia, it may refer to duffing (Clack, 2018). In South Africa, livestock theft is categorized as a property crime (SAPS, 2022). Livestock theft here refers to the stealing of livestock (cattle, sheep, goat, horse, donkey, pig, etc.) belonging to another person. The purposes may be for selling, keeping, raising or slaughtering livestock, or for other socio-economic benefits. There is no universal definition or reference as to the identity of a livestock thief. It could be anyone, for instance, a neighbour, farmer, auctioneer, law enforcement officer, youth, foreign national, etc. (Clack, 2018).

A global scan of literature reveals that there is no ‘one-size-fits-all’ when it comes to studying or researching livestock theft. Across the world, livestock theft manifests itself in various scales and dimensions. There is a variety of environmental, sociological, political, cultural and economic dimensions that influence livestock theft. In this regard, various authors, scholars/academics and researchers have attempted to study livestock theft from different theoretical/model perspectives. Through the application or explanation of theories, they have sought to study the nature, dimensions, causes, motives, and preventative strategies of livestock theft. For instance, Doorewaard (2020) researched various factors about livestock theft. These include when and where livestock thefts occur and whether livestock thefts are spontaneous or planned. Doorewaard (2020) further studied different types of perpetrators (individual or groups), loopholes, factors, causes and motives of livestock theft, and theories to explain the associated criminal behaviour.

Breetzke et al. (2023) applied the Routine Activity Theory to explore the causal and contributory factors in the occurrence of livestock thefts. In contrast, Clack (2015) applied a combination of Routine Activity Theory, Crime Pattern Theory, Rational Choice Theory and Buffer Zone to analyse livestock theft cases in South Africa. Doorewaard (2020), in her study on criminal behaviour associated with livestock theft, applied the same criminological theories. Masuku and Motlalekgosi (2022) explain how the Broken Window Theory and Social Bond Theory can be used to study the phenomenon of livestock theft. Müller (2016) highlights the applicability of crime prevention models to livestock thefts. Sidebottom (2013) applies CRAVED (Concealable, Removable, Available, Valuable, Enjoyable, and Disposable) theory to explain variations in livestock theft. Mears et al. (2007) applies Crime Opportunity Theory to study theft of livestock. Müller (2016) explains how Neutralisation Theory fits into the context of livestock thefts. Müller (2016) also demonstrates how the Disaster Pressure and Release (PAR) model can be applied to study livestock thefts. In the same paper, Müller (2016) explains the models of combating crime in the context of livestock thefts.

The highlight of these studies is that the theories provide a framework for researching livestock theft crimes in terms of six basic questions: "what", "where (location)", "when", "who", "how", and "why". The theories applicable to livestock theft crimes can be categorized into criminology, disaster management, sociology, physiology and economics, as summarised in table 5 below. In table 5 below, the terms Concept 1, Concept 2, Concept 2, Concept 3, Concept 4, Concept 5 refer to the building blocks of a theory.

Table 5: Theories and models previously applied to research on livestock theft

Theory or Model	Category	Concept 1	Concept 2	Concept 2	Concept 3	Concept 4	Concept 5
Routine Activity Theory (Breetzke et al., 2023).	Criminology.	Offender.	Suitable target.	Absence of guardian.	--------	--------	--------
Crime Pattern Theory (Clack, 2015).	Criminology.	Nodes.	Paths.	Edges.	--------	--------	--------
Rational Choice Theory (Clack, 2015).	Criminology, Eeconomics, Psychology, Philosophy, Politics.	Rational actors.	Self interest.	Invisible hand.	--------	--------	--------
General Strain Theory (Doorewaard, 2020).	Criminology.	Failure to achieve positively valued goals.	Removal of positive stimuli.	Introduction of negative stimuli.	--------	--------	--------
Broken Window Theory (Masuku and Motlalekgosi, 2022).	Criminology.	Informal social controls.	Role of fear.	Difference with zero tolerance.	--------	--------	--------
Social Bond Theory.	Criminology.	Attachment.	Commitment.	Involvement.	Common values.	--------	--------
Social Learning Theory Learned experiences.	Physiology.	Learned experiences.	Attention.	Retention.	Reproduction .	Motivation.	
Buffer Zone Theory (Clack, 2015).	Criminology.	Topographic factors.	--------	--------	--------	--------	--------
CRAVED theory (Sidebottom, 2013).	Criminology.	Concealable.	Removable.	Available.	Valuable.	Enjoyable.	Disposable.
Neutralisation Theory (Müller, 2016).	Criminology.	Denial of responsibility.	Denial of injury.	Denial of the victim.	Condemnatio n of the condemners.	Appeals to higher loyalties.	--------
Crime Prevention Models (Müller, 2016).	Criminology.	Conservative model.	Liberal model.	Radical model.	--------	--------	--------
PAR Model (Müller, 2016).	Disaster Management.	Unsafe conditions	Dynamic pressures.	Root causes.			

Source: Author's own illustration based on synthesised theories and models previously applied to research on livestock theft

Table 6: South African research on livestock theft

Author	Main Theme	Theory/Model	Method	Key Highlights/Findings
Breetzke et al. (2023).	Contributory factors to the occurrence of livestock thefts.	Criminological theories.	Interviews. Group conversations.	Economic factors are the main drivers of livestock-theft.
Maluleke et al. (2022).	Livestock theft contributory factors during the lockdown.	Not specified.	Literature review.	Restricted patrolling of livestock farms in South Africa limited livestock branding and tattooing. Inadequate use of technologies.
Maluleke (2021).	Perspectives on livestock theft prevention.	Not specified.	Focus Groups. Key Informants. Interviews. Observation Schedules.	Lack of appropriate preventative measures. Loss of confidence toward the police.
Zantsi S.[I]; Nkunjana (2021).	Possibilities for using animal tracking devices to mitigate stock theft.	Not specified.	Literature review.	Empirical research on the level of awareness among communal (smallholders and sustenance) about GPS animal tracking devices and whether these farmers would be willing to adopt this technology does not exist.
Pasiwe et al. (2021).	Socio-economic impact of stock theft on victims.	Criminological theories.	Interviews.	Victims of livestock theft are more likely to suffer from psychological stress and Post-Traumatic Stress Disorder (PTSD).
Masuku & Motlalekgosi (2021).	Community policing and livestock theft.	Criminological theories.	Interviews.	Lack of community involvement in the fight against stock theft. Poor relationship between the SAPS and the community in combating stock theft.
Doorewaard (2020).	Criminal behaviour associated with livestock theft.	Criminological theories.	Interviews. Dockets.	Livestock theft is of organised nature, and perpetrators come from diverse backgrounds.
Geldenhuys (2020).	Livestock theft: a costly, cruel crime.	Not specified.	Secondary data.	Organised crime. Cross-border stock theft. Scams associated with. livestock theft. Violence associated with livestock theft. Technology in stock theft. Identification of livestock. DNA technology. Policing problems.

Author	Main Theme	Theory/Model	Method	Key Highlights/Findings
Maluleke (2020).	Drones in policing livestock theft.	Not specified.	Interviews.	Inadequate related knowledge and application of the use of drones.
WA & Bahta (2019).	Estimate Financial Impact of livestock theft in one province of South Africa.	Not specified.	Interviews. Questionnaires. Quantification of direct and indirect costs.	Estimated total was R 303 858 556.
Maluleke (2019).	Cross-border crimes.	Not specified.	Systematic review of literature.	Livestock theft is a common cross-border crime and highly organised in nature.
Maluleke (2019).	DNA evidence to link a suspect to stock theft scenes.	Not specified.	Interviews.	Accuracy of DNA application is beyond doubt, when done in the correct way.
Clack (2018).	Livestock is a global problem.	Not specified.	Secondary data.	Livestock theft differs in extent between regions, provinces, countries and continents.
Clack (2018).	Livestock thefts as primary crimes in rural areas.	Not specified.	Secondary data.	Livestock theft represents the biggest economic and crime impact on rural economies.
Clack (2018).	Non-reporting of livestock theft by farmers.	Not specified.	Secondary data.	Various reasons for the non-reporting.
Lombard & van Niekerk (2017).	Role of unmarked livestock.	Not specified.	Secondary data.	Unmarked livestock can cause stock thieves to be found innocent in court, because it is impossible to prove ownership of the animals.
National Stock Theft Prevention Forum (2015).	Guide to the prevention and handling of livestock theft	Not specified.	Secondary data.	Safety tips. Livestock branding. Relevant legislation.
Maluleke et al. (2016).	Extent, impact, dark figures and problems areas of stock theft.	Not specified.	Secondary Data. Focus Group Discussions (FGD), Interviews with the Key Informants (KII) and Observations schedule through court session attendance.	There is no single solution tailor-made to fight against livestock theft.
Muller (2016).	Magnitude of livestock theft.	Combination of PAR model and several models.	Questionnaires.	Various factors contribute to livestock theft.

Author	Main Theme	Theory/Model	Method	Key Highlights/Findings
Lombard (2016).	Quantify the financial impact of livestock theft.	Valuing losses and modelling cost.	Questionnaires. Quantification of the direct and indirect costs of losses to livestock theft.	Livestock theft has a major financial impact on the livestock industry.
Clack (2015).	Uniqueness of livestock theft as a rural crime.	Environmental criminology theories.	Livestock theft cases.	Livestock theft needs to be attended to in a more specialised manner than other crimes against property in rural areas.
Clack (2015)	Role of social media in livestock theft.	Not specified.	Case studies from the Facebook social media group.	Identify possible livestock theft suspects. Identify the interrelationships between the various role-players. Contribution to the apprehension of offenders. Locating of stolen livestock and the identification and tracking of owners.
Maluleke et al. (2014).	Assessment of Policing and Prevention Strategies of Stock Theft.	Not specified.	Interviews.	Cloud of no confidence exists toward the police amongst the affected livestock farmers and community members.
Clack (2013).	Extent of Livestock Theft.	Not specified.	Exploring the reported cases of livestock theft.	Create awareness of livestock theft. Recommendations for possible new research topics.
Zwane et al. (2013).	Role of DNA in livestock theft.	Not specified.	Literature Review.	Nationally, animal forensic and dispute cases have been resolved through DNA. DNA forensics is a long and costly process.

Source: Author's own illustration based on the scholars and year of publications that are listed in the first column.

4.5. Prevalence, Magnitude, Nature and Dynamics of Livestock Theft

Livestock theft is one of the biggest threats to the stability of the livestock farming sector in South Africa. Stock theft affects both commercial and communal farmers in South Africa. Cattle, sheep and goats are the most stolen livestock in the country. Cross-border livestock theft is prevalent in KwaZulu-Natal, Free State, Limpopo and Eastern Cape provinces. Stolen livestock may be smuggled into such neighbouring countries as Lesotho, Swaziland and Mozambique (Stock Theft Preventative Forum, 2015; SAPS, 2015; PMG, 2010).

The 2011 – 2021 crime statistics from SAPS indicate that there were more than 25 000 reported cases of livestock theft in 2017 in the country. This number increased to 28 849 and 29 672 in the years 2018 and 2019 respectively. Over the past ten years, the Eastern Cape, KwaZulu-Natal and Free State provinces recorded the highest numbers of livestock theft cases. Table 7 below provides a summary of livestock theft statistics from 2011 to 2021 nationally and in each province.

Table 7: Livestock theft statistics - reported cases from 2011 to 2021 in South Africa

	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	2020/2021
Eastern Cape	6 839	6 530	5 808	6 087	5 809	6 023	6 217	6 736	6 800	6 399
Free State	4 487	4 175	4 051	3 527	3 466	3 677	4 032	4 066	3 785	3 317
KwaZulu-Natal	6 508	6 018	5 754	5 956	5 731	5 959	6 322	6 380	6 252	6 059
Limpopo	1 729	1 568	1 567	1 666	1 756	1 956	2 187	2 396	2 331	1 970
Mpumalanga	2 481	2 254	2 182	2 192	2 337	2 867	3 135	3 255	2 987	2 706
North West	2 668	2 714	2 388	2 574	2 605	3 192	3 447	3 557	3 005	2 693
Northern Cape	1 418	1 584	1 211	1 331	1 332	1 356	1 558	1 313	1 259	1 221
Western Cape	876	924	789	831	861	885	953	975	1 011	925
Gauteng	605	698	784	801	818	987	998	994	988	1 020
South Africa	**27 611**	**26 465**	**24 534**	**24 965**	**24 715**	**26 902**	**28 849**	**29 672**	**28 418**	**26 310**

Source: SAPS (2022)

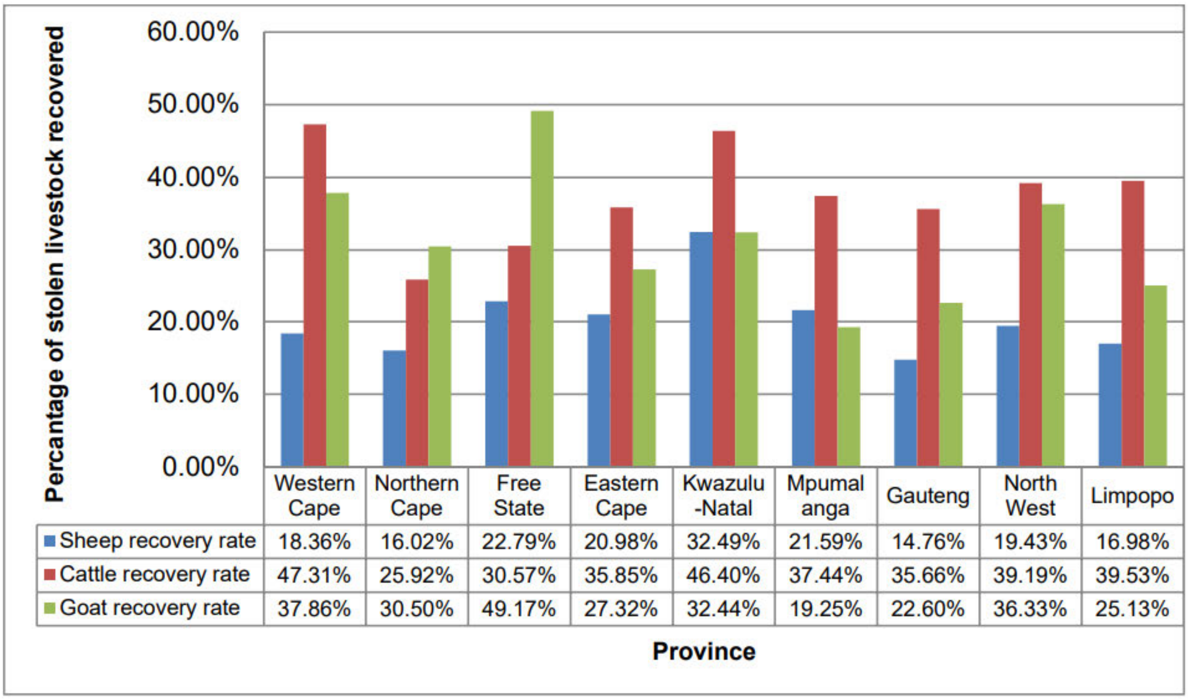
In the Eastern Cape Province, major livestock theft hotspots include areas of Maluti, Tsolo, Sulenkama, Qumbu, Bityi, Mthatha, Ngcobo and Tsolo. In KwaZulu-Natal, the major hotspots include areas of Taylors Halt, Amangwane and Dannhauser. The Emerlo area and Amersfoort area are the livestock theft hotspots in Mpumalanga. In Free Sate, livestock is very prevalent in both the Bethlehem and Harrismith areas (SAPS, 2022). Table 8 below shows the top 10 livestock theft hotspots areas in South Africa in 2021.

Table 8: Top ten livestock theft hotspots in South Africa in 2021

Area	Province	Number of livestock theft cases reported to the SAPS
Qumbu	Eastern Cape	320
Sulenkama	Eastern Cape	319
Taylors Halt	Kwazulu-Natal	283
Mthatha	Eastern Cape	281
Bityi	Eastern Cape	265
Mount Fere	Eastern Cape	243
Maluti	Eastern Cape	228
Tsolo	Eastern Cape	208
Amangwane	Kwazulu-Natal	203
Dannhauser	Kwazulu-Natal	188
Total		**2538**

Source: SAPS (2022)

It is worth noting that the statistics presented in Table 8 are based on the number of cases reported; not on the overall-total number of animals (cattle, sheep or goats) stolen in the country. In some instances, it may happen that a large number of livestock (for instance, sheep) get stolen, and this is reported under one case with one case number. With these cases-based figures provided by SAPS, it is difficult to accurately calculate exactly how many livestock in total were stolen within a specific year in the country. The non-reporting of stolen livestock further aggravates the situation. According to Clack (2018) some victims do not report livestock theft. This means not reporting to the SAPS, the local traditional authority (chief or headmen), community policing or neighbourhood watch. This leads to the inaccurate national statistics on the recovery rates of stolen livestock in the country. In South Africa, the livestock recovery rates are mostly based on estimated figures. The estimated national average recovery rate for the financial year 2013/2014 for cattle, sheep and goats combined was compiled by NSTPF (2014). This is shown in Figure 5 below. The figure shows that the estimated recovery rates of stolen livestock differ between provinces, and also differ between livestock breeds (cattle, sheep and goats). On average, the national recovery rate of stolen livestock (cattle, sheep and goats) was about 34% for 2013/2014. This figure indicates that most stolen livestock are not recovered at all or are not reported as ‘recovered’.



	Western Cape	Northern Cape	Free State	Eastern Cape	Kwazulu -Natal	Mpumal anga	Gauteng	North West	Limpopo
Sheep recovery rate	18.36%	16.02%	22.79%	20.98%	32.49%	21.59%	14.76%	19.43%	16.98%
Cattle recovery rate	47.31%	25.92%	30.57%	35.85%	46.40%	37.44%	35.66%	39.19%	39.53%
Goat recovery rate	37.86%	30.50%	49.17%	27.32%	32.44%	19.25%	22.60%	36.33%	25.13%

Figure 5: Percentage of stolen livestock recovered per province in 2013/2014
Source: STPF (2014)

Visible Policing (2019) reported that livestock has become an organised crime as well as a cross-border crime. Various authors, scholars/academics and researchers concur with Visible Policing (2019). For instance, Doorewaard (2020), Chelin (2019), Maluleke (2018), Muller (2016), Clack (2015), Doorewaard et al. (2015) all report that there is a growing trend of organised livestock thefts with criminal networks. This occurs in different parts of neighbouring countries where thieves from outside the country are working together with South Africans to sell stolen animals. In the context of this research study, "organized crime" refers to a group of two or more persons who are collectively engaged in livestock theft. The group could be in a structured form or just a non-random group of persons formed for the immediate theft of livestock. The group could be operating nationally or internationally or a collaboration of national and international criminal syndicates. It is believed that the organised criminal groups are responsible for theft of large numbers of livestock, particularly valuable animals (cattle, sheep and goats) (Clack, 2018).

Malule and Dlamini (2019), Clack (2015), Doorewaard et al. (2015), Hübschle (2010), and PMG (2010) point out that there is an ongoing trend of coordinated groups in the country stealing large numbers of livestock. This trend manifests in various forms. For instance, Dooerward (2020) empirically found that there were instances of 10 to 60 cattle stolen by a group of two or more individuals in a planned manner. In the same empirical study, Dooerward (2020) found that a group of two or more individuals was involved in the stealing of 20 sheep. Considering these empirical findings, there is a clear indication that livestock thefts are committed and co-ordinated by well-organised criminal syndicate networks. Clack (2018) believes that about 80% of livestock theft involves some form of organised crime while about 20% is for survival purposes. Chelin (2019, p.1) argues that livestock theft in the country involves some form of organised groups: "Usually the syndicates have a scout who watches the movement of the livestock and alerts the criminals. At the opportune time, the individuals illegally access the property and steal the animals which are then loaded onto trucks and driven away".

The organised nature of livestock theft crime in the country is further aggravated by the collusion among various actors such as farmers, farmer workers, livestock thieves, drug cartels, buyers, law enforcement officers, and foreign nationals. Chelin (2019) avers that "there have also been instances where farm workers and farmers were involved in stock theft by colluding with livestock theft syndicates". ENCA (2020) reports that there were allegations of police collusion in the theft of livestock in one of the towns of the Free State province. The Economist (2017), and Donnermeyer (2016) point out corruption as one of the driving forces behind the collusion between law enforcement officers and livestock thieves. Molefhi (2015) reports that unemployed youths from Botswana colluded with youth from South Africa to steal livestock and sell it for drug money. It was also reported that livestock thieves from South Africa were collaborating with their counterparts from Lesotho with whom they exchanged stolen livestock (The Weekly, 2013).

The organised "mafia syndicate" nature of livestock theft in the country is evident in the tactics adopted, equipment used, and modes of transportation utilised when stealing livestock. Doorewaard (2020), Müller (2015), Famers Weekly Magazine (2015a), Stock Theft Preventative Forum (2015), Maluleke et al. (2014), Clack (2013), Hübschle 2010), PMG (2010), and SAPeople.com (2010) indicate that livestock thieves employ various tactics when stealing livestock. The reported tactics and strategies include:

- Committing burglary into agricultural households, and emptying the kraals, taking away a group of livestock, or all the livestock. Thieves usually employ this tactic at night.
- Killing and slaughtering the unattended/stray livestock on the grazing fields for the purpose of self-acquiring meat or selling the meat to the markets.
- Breaking into the farm fences, and taking away a group of livestock, or all the livestock.
- Taking advantage of stray livestock by snatching them.
- Syndicates in collaboration with law enforcement officers, and thus bribing the law enforcement officers.
- Transnational collaboration among local syndicates and neighbouring countries syndicates.
- Use of violence or threat of violence.
- Use of so-called runners who are paid as little as R500 per night.

- Stolen livestock hidden for a while or immediately loaded onto bakkies and trailers to be distributed.
- Rebranding the stolen livestock for the purposing of keeping it or selling it.
- Knowledge and information about the targeted farming community.
- Knowledge or background information on targeted livestock.
- Recruitment of so-called runners.
- Herding the livestock using horses or on foot.

Doorewaard (2020) empirically found that livestock thieves utilise various equipment when stealing livestock. These include tongs, cutters, pliers, knives, ropes, broken bottles, and printing machines to falsify documents. Moreover, thieves use branding equipment, weapons (e.g. guns), night vision binoculars and false aliases (e.g. use another person's identity documents). The use of transportation vehicles such as cars, vans, mini buses and trucks for livestock theft is common in the country. These techniques enable the thieves to snatch livestock for the purpose of selling it to the individual buyers, abattoirs or other livestock farmers. Horses and donkeys are also used to facilitate the stealing of livestock.

The patterns of the organized nature of livestock theft in the country can also be observed in the (i) outlets of stolen livestock, (ii) manner in which the stolen livestock are moving across the country, and (iii) disposal mechanisms. According to Müller (2015), stolen livestock end up in the weddings, funerals, cultural ceremonies, slaughter houses/abattoirs, farmsteads, auctions, and informal markets, across the country, and in neighboring countries. The empirical findings obtained by Doorewaard (2020) concur with Müller (2015), when she found that the disposal mechanics employed by thieves included sale of stolen livestock, own consumption, and rituals.

In terms of season and time occurrence of livestock in the country, Müller (2015) indicates that livestock theft takes place throughout the year. Most incidences of livestock theft are committed at night. Doorewaard (2020), and Müller (2015) mentioned that there are periods when livestock thieves tend to utilise the full moon because it is easier for them to identify the targeted livestock. In terms of area/setting/place of theft, Doorewaard (2020), Clack (2018), Maluleke (2018) reported that most areas from which the livestock were taken included camps, grazing areas, farmsteads, cattle posts, and kraals.

4.6. Laws Pertaining to the Livestock Sector and Theft of Livestock

The South African government has passed a number of laws pertaining to livestock. These laws include: Animal Identification Act; Stock Theft Act; Animal Protection Act; Illegal Hunting with Dogs; (iv) Pounds Bill; Fencing Act; Trespass Act; Animal Health Act; South African Abattoir Corporation Act;

Fines Adjustment Act; and Movement of Animals and Animal Produce Bill (Government of South Africa, 2016).

- **Animal Identification Act:** The law stipulates that anyone who owns cattle, sheep and goats is required to mark them. The law stipulates that it is compulsory to mark all cattle, sheep, goats and pigs. The law stipulates that identification marks can be done by hot iron branding, freeze branding or tattooing. An identification mark consists of not more than three letters of the alphabet or symbols. Livestock owners are required to apply for identification marks by sending documentation to Pretoria. The identification marks are then placed on the National Register of Animal Identification System (AIS). The purpose of the law is to provide legal proof of livestock belonging to the owner (Government of South Africa, 2015).
- **Stock Theft Act**: The law stipulates that anyone who fails to give satisfactory account of possession of stock through evidence shall be guilty of offence. The purpose of the law is to facilitate and enforce the persecution of livestock thieves and perpetrators of livestock theft (Government of South Africa, 2016).
- **Animals Protection Act:** The law stipulates that anyone who ill-treats animals shall be guilty of an offence. This includes overloading, overdriving, neglecting, torturing, infuriating, confining, chaining and starving livestock. The purpose of the law is to safeguard livestock against ill-treatment actions (Government of South Africa, 2016).
- **Animals Pounds Bill:** An animal pound is a place where stray, lost, abandoned or surrendered livestock are brought in and kept. The purpose of the law is to regulate the national norms, standards for impounding of animals. Also, the law seeks to regulate the registration, establishment and administration of animal pounds (Government of South Africa, 2016).
- **Animal Health Act:** The purpose of the law is to (i) provide measures to promote animal health, (ii) control animal diseases, (iii) establish animal health schemes and (iv) regulate the importation and exportation of animals. The law further regulates research, experiments and investigations on animals. For example, the law stipulates that no person may without the written authority of the national executive officer conduct any investigation, experiment or research with any vaccine, serum, toxin, antitoxin, antigen or other biological product wholly or partially on/from any animal (Government of South Africa, 2016).
- **Movement of Animals and Animal Produce Bill:** The purpose of the law is to: specifically protect the South African livestock owners from the theft of livestock; combat and investigate crimes concerning livestock; and monitor the movement of livestock within and across the borders of the Republic of South Africa (DALRRD, 2016).

- **Private Security Industry Regulation Act:** The Act regulates the private security industry; establishes a regulatory authority; and provides for matters connected therewith (DALRRD, 2022).
- **Criminal Procedure Act:** The Act makes provision for procedures and related matters in criminal proceedings, including matters related to livestock theft (Government of South Africa, 2016).

4.7. Strategies, Programmes and Structures to Combat Livestock Theft

South Africa has various initiatives at the national level, provincial level and local (municipal) level aimed at addressing theft of livestock. These initiatives include: National Rural Strategy; Stock Theft Preventative Forums; Stock Theft Information Centres; and SAPS (Visible Policing, 2019)

- **National Rural Safety Strategy**: The South African government developed a Rural Safety Strategy between 2011 to 2014 in an effort to address the ongoing violent crimes perpetrated against rural communities, as well as the high levels of livestock stock theft. Some of the key objectives of the strategy include: improving safety and security within the entire rural environment; enhancing communication between the police and farming communities in the rural areas; and establishing partnerships between the police and rural communities (Visible Policing, 2019).
- **Stock Theft Preventative Forums:** The escalation of livestock theft in South Africa prompted the Red Meat Producers organisation to establish stock theft preventative forums at national and provincial levels. The aim of the forums is to establish an organised representative structure against livestock theft. The members of the forum include people from the SAPS, farming communities, Department of Correctional Services, Department of Agriculture, and Department of Defence Force (Stock Theft Preventative Forum, 2015).
- **Stock Theft Information Centres:** The national instruction obliges the national theft units to establish a Stock Theft Information Centre in their service areas in collaboration with livestock owners. One of the aims of the Stock Theft Information Centres is to collect information on the incidences of livestock theft and transmit it to the SAPS.
- **Stock Theft Units:** STUs are special units within the South African Police Service. The role of STUs is to record, follow-up and investigate the reported cases of livestock theft.

4.8. Methods and Technological Systems Employed by Farmers against Livestock Theft

A survey conducted by Lombard and van Niekerk (2016) found that the preferred methods to control livestock theft include actively patrolling, implementing access control, livestock guards, guard dogs, stock theft collars, and cameras. Similar patterns were reported by Lombard et al. (2017), Farmer`s Weekly Magazine (2015b); Stock Theft Preventative Forum (2015) and Meissner et al. (2013). Moreover, studies have shown the use of kraaling livestock, fencing, operating neighbourhood watch initiatives, locking ramps in camps, sharing grazing areas by communities, installing lights and alarms and employing herdsmen to control livestock theft. This is further explained below.

- **Kraals**: Kraals are most common enclosure for cattle, sheep and goats, especially in the rural areas (Farmer`s Weekly Magazine, 2015b).
- **Fencing:** According to Farmer`s Weekly Magazine (2015b), some livestock farmers erect fences to keep livestock within certain areas, or out of other areas and for security. The erection of fences is most common in the commercial farming sector (Farmer`s Weekly Magazine, 2015).
- **Watchdogs:** A survey conducted by Farmer`s Weekly Magazine revealed that some livestock farmers use watchdogs to safeguard their livestock (Farmer`s Weekly Magazine, 2015b).
- **Neighbourhood watch:** A survey conducted by Farmer`s Weekly Magazine revealed that some livestock farmers use neighbourhood watch to safeguard their livestock Farmer`s (Famer`s Weekly Magazine, 2015b).
- **Shared grazing areas by communities:** In the communal farming sector, the sharing of grazing areas by the communities is a common practice (Meissner et al., 2013).
- **Surveillance cameras:** A survey conducted by Farmer`s Weekly Magazine revealed that some livestock farmers use surveillance cameras to safeguard their livestock Farmer`s (Famer`s Weekly Magazine, 2015b).
- **Security guards:** According to Lombard et al. (2017), a survey conducted by Farmer`s Weekly Magazine found that some livestock farmers use security guards to safeguard their livestock.
- **Frequently counting animals:** Some livestock count their livestock in the morning before releasing them for grazing and in the afternoon after grazing (Farmer`s Weekly Magazine, 2015b).
- **Electrified fences:** According to Lombard et al. (2017), some farmers were using electrified fences to safeguard their livestock against theft.

- **Herdsmen:** Livestock farmers use herdsmen to herd animals in the veld (Stock Theft Preventative Forum, 2015).
- **Stock theft collars:** Collars are placed around the necks of a few animals in the herd. Due to the high costs associated with these devices and their peripheral systems, these devices are mainly used by large scale commercial livestock farmers. Furthermore, the value of utilising these collars with GPS tracing and GSM devices is still unknown to many communal livestock owners who prefer to use conventional methods such as branding and tattooing (Maluleke, 2018).

4.9. Livestock Identification Methods Adopted by Livestock Farmers

At the time of the research study, South Africa had not rolled out Digital Identifications (IDs) for cattle, sheep and goats. The most common method of livestock identification adopted by the South African smallholder livestock farmers and subsistence livestock farmers is the non-digital (manual traditional/convention) animal branding. Katikati & Fourie (2019), Maluleke (2018), Clack (2015), and Stock Theft Preventative Forum (2015) found that most livestock farmers use hot iron branding to mark cattle, and brand their sheep and goats by means of ear notch and tail notch. These scholars highlight that temporary marks such as paint on the sheep`s rear and goats` rear are also common identification methods in the communal livestock sector. In case of livestock-theft, livestock holders particularly in the communal sector have to rely on conventional identification methods to track and recovery the stolen livestock.

The Animal Identification Act makes it compulsory for cattle, sheep and goats to be marked (DALRRD, 2016). The law sets out procedures and guidelines for livestock identification and on how livestock should be marked:

- **All identification marks must be registered:** All owners of cattle, sheep and goats are required to apply for registered identification marks at the office of the registrar of animals. The registered marks are placed on the National Register of Animal Identification System (AIS).
- **Cattle Identification Marks:** The law sets out that cattle can be marked, tattooed or branded at the age of 6 months. Tattooing of cattle should be in the left or right ear. Branding of cattle should be on any clearly visible part, with the exception of the neck. The characters of a tattoo may not be larger than 20mm (high or wide). The mark may have 1, 2 or 3 characters. Characters must be put next to each other. Brand marks must be between 40mm and 100mm at the widest and highest part.

- **Sheep and Goat Identification Marks:** The law states that the first owner can put the tattoo in the left ear, the second owner in the right ear.

The Animal Identification Act law cites various advantages of legal identification marks. These advantages include (DALRRD, 2016):

- Visible deterrent – stock thieves are more inclined to steel animals that are not marked.
- Positive identification.
- Positive proof of ownership.
- More effective policing.
- More effective recovery rate.
- Enable tracing.
- A legal identification mark is very useful – if stolen or lost animals are found, it will be possible to find the owner.

4.10. Constraints faced by SAPS in Dealing with Livestock Theft

As already stated in previous sections, there is a Stock Theft Unit in the SAPS. The Unit operates in all the provinces and districts where livestock theft is prevalent. The SAPS face a number of challenges when it comes to crime prevention and livestock theft investigations (Doorewaard, 2020; Chelin, 2019; Lombard, 2019; Bunei, 2017; Maluleke 2016; Clack & Schutte, 2015). Table 9 provides a synthesis of the findings from studies conducted by these scholars. The researcher has designed categories of (i) human resources, (ii) technical resources and costs, (iii) relations between SAPS, farming communities, and other role players, and (iv) livestock recovery and justice process.

Table 9: Constraints and challenges faced by SAPS in relation to livestock theft

Human Resources	**Technical Resources and Costs**	**Relations between SAPS, farming communities, and other role players**	**Livestock recovery and justice process**
• Vacant positions in the SAPS create capacity problems, which leads to: • Shortage of Stock staff in the Stock Theft Units. • Shortage of the necessary expertise.	• Shortage of off-road vehicles. • High costs of helicopters to police the mountainous terrains. • High cost of impounding livestock.	• Poor cooperation and collaboration between law enforcement and farmers. • Corruption. • Collusion. • Non-reporting of livestock theft by victims. • Late reporting of cases by victims.	• Lack of evidence or witness to sustain and prosecute suspect of stock theft. • Use of poor branding marks by famers do not conclusively proof ownership. • Highly sophisticated criminals. • Loss of evidence when livestock is consumed. • DNA forensics is a long and costly process. • Reliance on ARC for DNA forensics.

Source: Author`s own illustration based on Doorewaard (2020), Chelin (2019), Lombard (2019), Bunei (2017), Maluleke & Mofokeng (2016), and Clack & Schutte (2015)

4.11. Addressing the Research Questions

One of the purposes of this chapter was to address the research questions posed in chapter one. The findings in relation to the research questions obtained in this chapter provide valuable insights into the information system components and features necessary for inclusion in the sought-after model for controlling livestock theft in country. Table 10 below provides a summary on how this chapter has addressed some of study`s research questions.

Table 10: Addressing the research questions – chapter 4

Research question	Key Findings in relation to theory variables
Research Question 1: How does livestock theft occur in South Africa?	Nature of crime: Organized crime. Actors: National and international criminal syndicates. Actants: Vehicles, horses, sophisticated equipment and tools, fake documentation. Translation: Various links of actors through sophisticated tactics and strategies. Network: 'Web' of sophisticated criminals.
Research Question 2: Who are the important actors involved 'in the fight against' livestock theft in South Africa?	Various actors with different interests, links and relations as discussed in section 4.3.
Research Question 3: How can the important actors be organized to control livestock theft in South Africa?	The multidisciplinary approach of various actors has been identified in the literature.
Research Question 4: What is the nature of use of livestock identification methods and tracking methods by the human actors for controlling, mitigating, or combating livestock theft in South Africa?	Various actants as discussed have been found in the literature, as discussed in section 4.10 and 4.11. This are mostly confined at local and farm level.
Research Question 5: Which ICTs have been adopted by the human actors involved 'in the fight against' livestock theft in South Africa?	Various actants in the form of ICT have been found, as discussed in section 4.11. These are mostly confined at local and farm level.
Research Question 8: What are the information system components required to develop a holistic and national livestock identification and tracking system for controlling livestock theft in South Africa?	Various information system components in the form of actors, actants, translation, and networks have been found in the literature.

Source: Author`s own illustration based on literature review and study`s research questions

4.12. Identified Gaps in the Literature

The identified gaps in the literature by this chapter can be classified in three categories, namely: theoretical perspective; methodological perspective; and perspective of research questions. From a theoretical perspective, none of the research studies that were carried out within the South African context used the Actor Network Theory (ANT). There are very few research studies on ICTs in relation to livestock theft in South Africa. Most scholars have researched the phenomenon of livestock theft from a criminological perspective and social perspective.

In terms of the research gap from a methodological perspective, none of the research studies that were carried out within the South African context employed the Design Science Research Methodology (DSRM). The use of DSRM in this current study is explained in Chapter Eight. Very few research studies adopted the triangulation method. None of the research studies adopted a combination of Scoping Review Method (SVM), snowball strategy, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method, and Critical Appraisal Skill Programme (CASP) as the framework to support the literature review. Triangulation methods, SVM, PRISMA, and CASP when used together strengthen the quality of research. The use and importance of this combination in this current study is detailed in Chapter Five.

There are two gaps that 'stand out' in terms of research questions. Visible Policing (2019) 'calls' for the multidisciplinary approach for a comprehensive and holistic strategy to support the creation of a safe rural environment that combats theft of livestock. Despite this 'call', none of the research studies proposed a comprehensive and national ICT-based model/solution of a livestock identification and tracking system. The efforts to control livestock theft by various actors are mostly confined at local and farm level. There is a lack of coordinated regional, provincial or national approach. These are some of the gaps that the current study seeks to fill.

4.13. Summary of Chapter Four

The crime statistics from SAPS show that livestock theft occurs in all the provinces of the country. This is a clear indication that livestock is a serious national problem. Cattle, sheep and goats are the most frequently stolen livestock in the country due to their significant socio-economic and cultural value. Cross-border theft of livestock into South Africa`s neighbouring countries is also common. Consequently, livestock theft threatens the socio-cultural and socio-economic stability of livestock farming sector in South Africa. Given the magnitude and impacts of livestock theft, this property crime should be one of the South African government`s priorities in terms of planning, policy reforms, interventions and resource allocations.

The South African government has passed a number of laws pertaining to the livestock sector and theft of livestock. The country has various programmes and initiatives and structures aimed at addressing theft of livestock. Despite these efforts, the country is still faced with a scourge of livestock theft. Despite the existing structures, there seems to be a lack of collaboration and coordination among the various stakeholders. As suggested by Bunei (2017), livestock theft needs a partnership-based collaboration and integrated approach if it is to be controlled.

Livestock farmers, especially in the communal sector use traditional or conventional livestock identification methods. These methods are ineffective and inefficient in dealing with livestock theft in the country. ICTs can play a role in the identification and tracking livestock for controlling theft. The ICT developments such as computers, drones, cloud computing, big data and analytics, mobile phones, and social media are important in addressing the problem of livestock theft. However, the South African research on livestock theft in relation to the ICT domain is very limited.

Livestock theft in the country has degenerated into an organized crime involving national and international syndicates. The tactics and equipment utilised by criminal network syndicates facilitate the easy rebranding of livestock, smuggling livestock into the neighbouring countries, illegal sale of livestock, illegal transportation of livestock, and faking livestock documentation. Given this information, any livestock identification method that is not permanent and tamper-proof will always be ineffective in counteracting livestock theft. To resolve this issue, a permanent and tamper-proof identification method should be prioritised.

In the next chapter, a further detailed literature review is provided. The purpose of the next chapter is to gain an in-depth understanding of the existing global research and debates relevant to ICT use to mitigate, control or prevent livestock theft. The next chapter provides literature analysis on livestock identification and tracking systems for mitigating, controlling, and preventing livestock theft.

CHAPTER 5

LITERATURE VIEW: LIVESTOCK IDENTIFICATION AND TRACKING

5.1. Introduction

This is the third and last of three literature review chapters. The main purpose of this chapter is to gain an in-depth understanding of the existing global research and debates relevant to: (i) ICTs for addressing livestock theft, and (ii) livestock identification and tracking systems and technologies for mitigating, controlling and preventing livestock theft.

This chapter presents an overview and synthesis of related research studies conducted by other researchers and scholars across the world. The chapter provides implications of the synthesised information to the South African socio-economic, technological, environmental and cultural context. The implications also consider issues related to animal welfare and technology standards.

5.2. Framework to Support the Literature Review and Review Methods

The literature search for this chapter was initiated through the use of academic databases including the Web of Science (previously Web of Knowledge), Scopus, Science Direct, IEEE explorer, Sabinet, ACM Digital Library, AACE Digital Library, ProQuest, and a scholarly search engine known as Google Scholar. These databases were chosen because of their wide coverage of relevant literature and advanced bibliometric features such as suggesting related literature or citations. These databases allow for automatic importing of bibliography into the EndNote software. For this purpose, the researcher used the EndNote software to organise the references. The combinations of groups of various keywords such as 'ICT', 'IT', 'technology', 'livestock theft', 'stock theft', 'theft of livestock', 'livestock identification', 'animal identification', 'animal tracking', 'livestock tracking', 'stock theft', 'cattle rustling', 'cattle raiding', 'cattle duffing', and 'animal tracing' were used as search queries/keywords.

In chapter one, it was mentioned that this research study is qualitative in approach. Like any form of research, qualitative research has to conform to trustworthiness and validity. There are four criteria that are widely used to appraise the trustworthiness and validity of qualitative research, namely: credibility, dependability, confirmability and transferability (Macnee & McCabe, (2008). A combination of Scoping Review Method, snowball strategy, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method, and Critical Appraisal Skill Programme (CASP) was adopted as the framework to support the literature review for this chapter. The combination of these review methods was adopted in order to strengthen the credibility, dependability, confirmability and transferability for this research study. A combination of various methods strengthens the accuracy and transparent reporting of research findings. The justification for the selection and application of Scoping Review Method, snowball strategy, PRISMA, and CASP is described in the sub-sections below.

5.2.1. Scoping Review Method

The Scoping Review Method was chosen because it is less restrictive than other review methods. It allows for the redefinition of the literature search criteria as the researcher, author, academic or scholar becomes familiar with the existing literature on the subject area. According to Arksey & O'Malley (2005), the advantage of the Scoping Review Method is that: (i) it allows for in-depth and broad results when searching for literature information; (ii) it is guided by a requirement to identify all relevant literature regardless of study design, objectives, methods or theoretical model; and (iii) the search process in Scoping Review Method is not linear but iterative, which allows the researchers to engage with each stage in a reflexive way and, where necessary, repeat steps to ensure that the literature is covered in a comprehensive way.

5.2.2. Snowball Strategy

A snowball strategy is based on a thorough review of each article's references. It was used to identify other relevant peer-reviewed literature. The inclusion of snowball strategy in this chapter is in alignment with the explanations provided by Bread University of Applied Science (2022). According to Bread University of Applied Science (2022), snowball strategy is a process of tracking down references or citations in documents. The author then examines the bibliographies of these new publications to find yet more relevant titles (Bread University of Applied Science, 2022).

5.2.3. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

The PRISMA method was chosen because the researcher wanted to use a systematic structure to transparently report why the review was done, what the researcher did, and what the research found (search results). This is in line with the sentiments echoed by Gough et al. (2017), Moher et al. (2008) and Moher et al. (2009). They agree that the PRISMA method requires authors to prepare a transparent, complete, and accurate account of why the review was done, what they did, how studies were identified and selected and what they found. The workflow of the PRISMA for this chapter is described below.

1. **Identification:** At this stage, the literature search for this chapter was initiated through the use of academic databases, and Google Scholar. Search queries/keywords were used to initiate literature search. At this stage, records were manually screened, and then duplicate records were identified and removed. Since 'animal identification' has been a topic of interest for some years in the domains of e-agriculture and precision livestock farming, many journal articles on livestock identification were discovered. Journal articles on ICT-based

systems for tracking livestock are disparate and fragmented; and most of these articles are not based on the South African context. Journal articles that focused on proposing ICT-based systems as solutions for controlling livestock theft in the South African context are limited. Therefore, to mitigate these issues, the author decided to also include 'grey' and non-scholarly literature into the review. For this purpose, the search engine known as Google was used to search for reports, news, magazines, blogs, and other web items in English. Conference proceedings and online books were also searched using the Google search engine. Only relevant records published in English within of livestock identification or livestock tracking/tracking were selected for further review(screening).

2. **Screening:** Titles, abstracts, and keywords in the scholarly items (journal articles, conference papers and books), and non-scholarly items (reports, news, magazines and blogs) guided the screening and use of eligibility criteria. Only scholarly items and non-scholarly items that were relevant to two central themes mentioned in 4.1 were considered in the screening phase.
3. **Eligibility:** The Critical Appraisal Skill Programme (CASP) became relevant at this stage. At this stage, the researcher applied CASP to assess the eligibility and quality of articles.
4. **Included:** At this stage, records were grouped into three categories according to their relevance to the current research study: relevant records, partially relevant records, other relevant records. This made it possible to have a detailed study carried out on the articles during the qualitative synthesis activity in the final stage.

5.2.4. Critical Appraisal Skill Programme (CASP)

According to OAP Ltd (2022), CASP is useful when an author seeks to carefully and systematically examine a related published research study or paper regarding the top. The critical appraisal process allows the author to judge the trustworthiness and value of the published research study, on the one hand. On the other hand, the CASP enables the author to evaluate relevance and results in a particular context. This becomes essential for a quality evidence-based literature review (OAP Ltd, 2022). For this purpose, the "CASP Checklist" was used as a guide to carefully and systematically examine the research studies and papers used in this chapter. The "CASP Checklist" guide used in this chapter can be found in appendix M.

5.3. Livestock Identification

One of the known strategies for controlling theft of livestock is livestock identification. Livestock identification is an old tradition; it has been practised throughout the world for centuries to manage livestock (Bowling et al., 2008). Livestock identification refers to the combination of the identification and registration of an animal individually or as a group of animals, with a unique identifier. Livestock identification includes linking the livestock owner-details or the person responsible for the livestock to the livestock`s unique identifier (WOAH, 2022). Livestock registration refers to the collection, recording and securely storing livestock identification with owner-details into a centralised electronic database, and making information accessible and useable by the relevant/authorised stakeholders (Government of South Africa, 2022; WOAH, 2022). The personal details of the livestock owner or person responsible for the livestock would already exist in the national registry database. In the South African context, each person has a unique identification number or passport number that holds his/her personal information in the national registry known as the ‘Home Affairs’ database. During livestock registration, this information (unique identification number) could be auto-verified against ‘Home Affairs’ database and then linked to the animals` unique identifier. Also, through the GPS system, the physical address coordinates of the farm lots where livestock are kept can be linked to the animals` unique identifier.

Livestock identification provides many benefits to the livestock stakeholders and red meat value/supply chain in general. Having unique animal identifiers have been found to support livestock monitoring, tracking, recovery and proof of animal ownership. Identification plays an integral role in traceability of animals throughout the value chain. In cases of livestock theft and recovery of stolen livestock, animal identification techniques not only help keep a record of the animals but also aids communication between farmers and law enforcement agencies (WOAH, 2022; DALRRD, 2022; Bowling et al., 2008).

5.4. Animal Welfare and Livestock Identification Standards

WOAH (2022) defines animal welfare as the physical and mental well-being of an animal in relation to the surrounding conditions in which it lives. According to WOAH (2022), animal welfare is a complex and multi-faceted subject with scientific, technological, ethical, economic, cultural, social, religious and political dimensions. Livestock identification and tracking is one of the aspects that falls within these dimensions. Globally, civil societies have raised animal welfare concerns linked to animal identification and tracking (WOAH, 2022; FAO, 2017). For instance, in South Africa, the National Council of Societies for the Prevention of Cruelty to Animals (NSPCA), advocates for the prevention of cruelty against animals. Moreover, the NSPCA promotes kindness and care for the animal, including alleviation of their suffering (NSPCA, 2022). In response to the concerns and awareness raised by civil societies, animal welfare has become one of the priorities of both the World Organisation for Animal Health (WOAH) and Food and Agriculture Organization (FAO) (WOAH, 2022, FAO, 2017).

According to animal welfare guiding principles compiled by WOAH (2022) and FAO (2017), an animal is in a good state if it:

- is safe, free from pain, and able to express innate behaviour;
- is free from fear and distress;
- is coping with the conditions in which it lives;
- is healthy, well-nourished and comfortable in its environment;
- receives proper veterinary treatment;
- receives proper human handling and human slaughter;
- receives appropriate shelter;
- is free from heat stress or physical discomfort;
- is free from injury and disease; and
- is free to express normal patterns of behaviour.

When designing and developing a livestock identification and tracking system, animal welfare needs to be taken into consideration. Irrespective of whether the identification and registration of livestock involves primary (conventional) or secondary (electronic or biometric) methods, animal welfare issues should be addressed (WOAH, 2022; FAO, 2017).

In addition to animal welfare issues, WOAH (2022) and FAO (2017) recommend that livestock identification and registration be done in accordance with international standards that are based on the most recent scientific and technical information. The international standards include:

- **WOAH's and FAO's integrated and multipurpose approach:** The guidelines provide information on animal identification and recording, animal performance recording, animal traceability, and animal health procedures.
- **International Organisation for Standardisation (ISO):** The guidelines provide information on radio frequency identification of animals.
- **Institute of Electrical and Electronics Engineers (IEEE):** The guidelines provide information on communication methods and data formats for transducers (sensors and actuators) communicating with RFID tags and systems.
- **Global Veterinary Community (GVC) guidelines**: The guidelines provide detailed information on microchip identification.
- **International Committee on Animal Recording (ICAR) guidelines:** The guidelines provide detailed information on various aspects related to livestock identification, such as DNA technology, cattle recording, identification device certification, and data exchange.

5.5. Factors to Consider in Livestock Identification

Neary and Yager (2022) state that

> "when selecting forms of identification, consider the application methods for each type, along with visibility from a distance, equipment needed for application, cost, permanence, and how easy or difficult the method is to apply".

Their statement aligns with WOAH, 2022 & WOAH, 2018), in addition to animal welfare issues and international standards, identifying, selecting and implementing a livestock identification method should be informed by various criteria and factors. The criteria and factors include:

- **Visibility** – the identification method must be visual and readable by the naked eye at a distance if it is to serve as deterrent;
- **Registration** – the identification method must be registered with an independent authority;
- **Permanent** – the identification method must be permanent if it is to serve as positive identification;
- **Readability** – the identification method must be readable by scanners/readers;
- **Tamper-proof** – the identification method must be tamper-proof in order to prevent manipulation and fraud;
- **Loss-proof** – the identification method must have a loss-proof rate of less than 0.1% per annum;
- **Reaction-proof** – the identification method must be safe to the animal;
- **Consumers` safety** – the identification method must be safe to the consumer of final products – for example, meat or milk;
- **Cost/Affordability** – the identification method must be affordable to the majority of the intended group of users;
- **Database - Data Storage and Data Retrieval** – the identification method must be database compatible;
- **Upgradability** – the identification method must be upgradable, because technology changes rapidly;
- **Accuracy** – the identification method must be able to capture, process and record data accurately;
- **Reliability** – the identification method must be able to achieve the intended outcomes under similar conditions;
- **Adaptability** – due to rapid technological changes, adaptability of identification methods needs to be considered;
- **Security and Privacy** – the identification method must be able to deal with security issues;

- **Universality** – with regards to adopting a biometric identification method, the selected identifier must be available, and must be quantitatively measurable;
- **Distinctiveness/Uniqueness** – with regards to adopting a biometric identification method, any two individual animals, for example twin animals, should be different in terms biometric trait;
- **Permanence/time-immutable** – with regards to adopting a biometric identification method, the biometric trait should be sufficiently invariant over a certain period of time;
- **Collectability and measurable** – with regards to adopting a biometric identification method, the biometric trait should be quantitatively measurable;
- **Performance** – the measurement of the identification mark, numbers, code or biometric trait should be robust, accurate, fast and efficient;
- **Acceptability** – the extent to which the intended group of users are willing to accept the use of a particular identification method should be taken into consideration;
- **Circumvention** – the extent to which the identification marks/numbers/code can be manipulated by using fraudulent methods should be taken into consideration;
- **Harmless** – the identification method must be harmless to the animal; and
- **Scalability** – the identification method should have the ability to increase or decrease in response to the demand changes.

5.6. Livestock Identification Methods

Different types of animal identification methods exist. They can be grouped under three categories: (i) conventional methods; (ii) electronic methods; and (iii) biometric methods. The next sub-section discusses these methods. This section begins by discussing conventional/traditional/mechanical methods under sub-section, followed by and electronic methods, and then biometric methods. A summary of the advantages and disadvantages of each livestock identification type is provided in the tables under each sub-section.

5.6.1. Conventional, Traditional, or Mechanical Livestock Identification Methods

Various types of conventional, traditional, or mechanical livestock identification methods exist. The terms conventional, traditional and mechanical are used interchangeably. These forms of livestock identification include ear tags (metal and plastic), drawings and descriptions, paint marks, neck/collar tags, ear notching, tattooing, hot iron branding, and freeze branding. Each of the livestock identification methods has advantages and disadvantages as discussed in the next sub-sections.

5.6.1.1. Ear Tags (plastic and metal)

Plastic ear tags and metal ear tags are identification techniques that can be applied on cattle, sheep and goats. They are placed in the ear of an animal by hand or by using a special applicator (Barron et al., 2009; Ekuam, 2009). Plastic ear tags are the most widely used by the farmers in Africa. This identification technique is cost-effective and easy to apply on livestock. Another advantage of plastic tags over metal tags is that they are visible from a distance (Ekuam, 2009). However, both plastic tags and metal tags are not a robust and resilient identification method, because they are not tamper-proof (Barron et al., 2009; Ekuam, 2009). For instance, thieves can simply remove or alter the numbers and symbols on the plastic and metal or remove the ear tag completely. This may lead to difficulty in proving ownership of livestock in case of theft. Hence, ear tags are not a permanent livestock identification method, as they can be lost or torn out. According to Labuschagne (2021), it is also a common practice among livestock thieves to cut off animals' ears during livestock theft.

5.6.1.2. Collar Tags / Neck Chains

The terms collar tags and neck chains are used interchangeably. A collar tag is an identification technique that can be applied on cattle, sheep and goats. A collar tag is attached around the neck of an animal. One advantage of a neck collar tag is that it is cost-effective and relatively easy to apply on livestock. Similar to the ear tags, the biggest disadvantage of collar tags is that they do not offer a permanent and tamper-proof method for livestock identification (Ekuam, 2009). In terms of animal welfare, collar tags can be dangerous to the animal – the animal can be chocked by the collar.

5.6.1.3. Ear Notching

Ear notching is one of the widely used permanent animal identification by communal farmers in Africa (Nel, 2014; Farmer`s Weekly Magazine, 2014; Ekuam, 2009). It is applied by cutting V-shape or U-shape portions of an animal`s ear, thereby creating an identification. Ear notching is cost-effective and easy to apply (Ekuam, 2009; Nel, 2014). The biggest disadvantage of ear notching is the lack of scalability. Ear notching provides the limited number of coding combinations when cutting the V-shape or U-Shape from an ear (Nel, 2014). Though ear notching is a permeant identification method, it is easy to manipulate. Thieves can alter the existing coding identification by cutting another notch or simply cutting out the existing notch. Also, the flesh around the notches at the top or bottom of an ear can grow and the size of the notches will therefore change.

5.6.1.4. Hot Iron Branding

Hot iron branding is an identification method that is mostly applied on big livestock such as cattle, horses, mules and donkeys. It is applied by firmly placing a heated hot iron on the animal`s skin. This creates an identification brand as letters, symbols, pictography into the hide of an animal (WOAH, 2016). Though hot iron branding is a permanent identification and offers visibility from a distance, it is susceptible to tampering fraud, duplication and alteration. For example, thieves can easily alter the existing brand mark (Ekuam, 2009). According to WOAH standards, for hot iron branding to serve as part of a national livestock identification and tracking system, it should reflect WOAH animal welfare guidelines (WOAH, 216). Hot branding can be invasive and hurtful to the animal. Therefore, WOAH (2016) recommends that the branding process be accomplished quickly, expertly, and with the proper equipment.

5.6.1.5. Freeze Iron Branding

Freeze iron branding is a permanent animal identification technique that is mostly applied on large livestock such as cattle, horses, mule and donkeys. The functionality of freeze iron branding is similar to that of hot branding. However, unlike hot branding, freeze iron branding involves the use of a frozen iron at temperatures between -40 and -200 Celsius instead of burning the iron (National Stock Theft Prevention Forum, 2015; Ekuam, 2009). Similar to the hot iron branding, freeze iron branding does not offer a tamper-proof identification; thieves can change/alter the existing brand mark. Another disadvantage of freeze iron branding is the cost of equipment and liquid nitrogen or solidified carbon-dioxide and alcohol mixture required for cooling the iron (Ekuam, 2009).

5.6.1.6. Tattooing

Tattooing is a permanent animal identification technique that is mostly applied on small livestock such as sheep and goats. It is applied on livestock by placing the ink in the ear or on the neck of an animal, or in any visible part of animal`s body. The ear tattooing can be in the form of letters, numbers, symbols or a combination thereof (National Stock Theft Prevention Forum, 2015; Farmer`s Weekly Magazine, 2014; Ekuam, 2009). Although tattooing offers some degree of permanent identification, it has drawbacks. Tattoo identification can be easily altered, duplicated, and removed by thieves. Also, tattoo identification marks are difficult to read from a distance (Farmer`s Weekly Magazine, 2014; Ekuam, 2009).

5.6.1.7. Drawings and Descriptions

Drawings and Descriptions are a cost-effective and permanent animal identification technique that can be used on any type of livestock. The livestock owner, keeper, or farmer, as the case may be, draws the physical appearance of livestock on paper. Then the person keeps a record of drawings and descriptions that have been placed on the livestock. The drawings and descriptions of livestock can be scanned and stored into a central database. Some African communal farming farmers describe their livestock by colour or give names to their livestock, especially cattle and horses (Ekuam, 2009). The greatest disadvantage of drawings and descriptions is the context. For instance, different communities and cultures describe the colour of an animal differently. A cow that looks brown to one cultural group may not be described as brown by another cultural group.

5.6.1.8. Paint Branding

Paint branding is one of the temporary forms of marking and identifying livestock. It can also be applied with a livestock spray or a paint marking stick. It is usually applied to the animal`s left or right side or both sides. Some farming communities apply it to the animals from tail to head. Paint branding is easily accessible, inexpensive, easy and quick to apply, and visible from a distance. It can serve several purposes, such as segregating certain animals, pairing parents and offspring, and animal exhibitions during sales and auction (QC Supply, 2022).

5.6.1.9. Summary of Conventional, Traditional, or Mechanical Livestock Identification Methods

As we have seen in the previous sub-sections, there are many different livestock identification methods. Livestock farmers can select the one that works best for their operations. Each livestock identification method has its advantages and disadvantages. A summary of the discussed livestock identification methods in relation to the factors outlined in section 5.5 is provided in Table 11 below.

Table 11: Conventional/Traditional/Mechanical Livestock Identification Methods

	Readable at a distance	Tamper-proof	Loss-proof/fraud-proof	Safe to the animal	Safe to the consumer of final products (e.g. meat)	Affordability to the majority of farmers	Database Compatibility	Upgradability
Ear Tags (Plastic)	Yes.	No.	No.	Yes.	Yes.	Yes.	Yes, unique letters/numbers/symbols on the tag can be stored in central database.	Yes.
Ear Tag (Metal)	No.	No.	No.	Yes.	Yes.	Yes.	Yes, unique letters/numbers/symbols on the tag can be stored in central database.	Yes.
Neck/Collar Tags	No.	No.	No.	Debatable.	Yes.	Yes.	Yes, unique letters/numbers/symbols on the tag can be stored in the central database.	Yes.
Ear Notching	No.	No.	No. It can be changed/altered by thieves.	Yes.	Yes.	Yes.	No.	Difficult, due to limited combinations.
Hot Iron Branding	Yes.	No.	No. It can be changed/altered by thieves.	Yes, but invasive and hurtful/painful.	Yes.	Yes, but debatable.	Yes, unique numbers/symbols can be stored in central database.	Not recommended, due to invasive and hurtful nature to an animal.
Freeze Iron Branding	Yes.	No.	No. it can be changed/altered by thieves.	Yes, but invasive and hurtful.	Yes.	No.	Yes, unique letters/numbers/symbols can be stored in the central database.	Not recommended, due to invasive and hurtful nature to an animal.
Drawings & Descriptions	No.	No.		Yes.	Yes.	Yes.	Yes.	Yes.
Tattooing	No.	No.	No. It can be changed/altered by thieves.	Yes.	Yes.	Yes.	Yes, unique tattoo ink letters/numbers/symbols can be stored in the central database.	Yes.
Paint Marks	Yes.	No.	No.	Debatable. Paint can be toxic to the animal.	Yes.	Yes.	No.	Yes.

Source: Author`s illustration based on literature review

5.6.2. Electronic Livestock Identification Methods

Traditional methods of identifying livestock do not offer automated data transmission and recording. They are not suited for the unique identification of an individual animal, and therefore ineffective for automated tracking of livestock. Electronic methods have emerged as an alternative technology for identifying and tracking livestock in an automated manner (Awad, 2016). The advantage of electronic identification methods over conventional methods is that they are well suited for the unique and independent identification of each animal in a group. They offer automated data collection, capturing and recording information into the electronic database (Barry et al., 2011). The recorded data can be used for various decision-making processes.

The most common electronic livestock-identification technology is Radio Frequency Identification (RFID). The RFID technology refers to a wireless system comprised mainly of two components: tags and readers. The reader is a device that has one or more antennas that emit radio waves to and receive signals back from the tags. Tags are small mobile units that are attached to objects of interests, for example pet, livestock, car, equipment, etc. Tags are fitted with a silicon integrated circuit (microchip) attached to a radio antenna mounted on a substrate. Tags use radio waves to communicate their identity and other information to nearby readers. The reader processes the returned radio waves from a tag into a meaningful identification code. Readers can be mobile so that they can be carried by hand, or they can be mounted on a post or overhead or building. Tags can be passive or active. Passive tags are powered by the reader and do not have a battery, while active tags are powered by batteries. Tags can store a range of information from one serial number to several pages of data. An RFID system can be extended to include a computer sub-system. The reader would then pass the information in digital form to a computer sub-system (data acquisition system), for example a database or a flat file (FDA, 2021; Karmakar et al., 2016).

Some common uses for RFID applications include, but are not limited to, pet and livestock tracking, inventory control, asset tracking and equipment tracking, vehicle tracking, and retail sales (Jian & Wu, 2013). In South Africa, RFID technology is being used to identify and track non-animal objects in the government sector, academic sector and automotive sector. Some examples of institutions that use RFID technology for identifying and tracking objects include the Department of Home Affairs, University of South Africa (UNISA), and Toyota South Africa (Yusof & Saman, 2016; Mathaba et al., 2011). There is no wide-spread adoption and use of RFID technology among livestock farmers (both commercial and communal) found in the literature for livestock identification and tracking in South Africa.

In Europe and North America, RFID is the most widely adopted electronic technology for livestock identification (Floyd, 2015; Khoo, 2010). To automate the identification of livestock, animals are fitted identifiers tags, bolus or microchips. Unlike the barcode technology that requires line of sight, RFID technology is considered to be beneficial because it does not require line of sight. With an RFID system it is possible to read, write and update digital information meters away from the RFID reader. Another advantage of RFID technology is the possibility to read multiple tags simultaneously. Integrating RFID, IoT sensors and GPS technology allows for the identification, behaviour and position of the livestock to be visualised on a mobile application or web application in a control centre through data remitted wirelessly (Awad, 2016). However, RFID has some disadvantages, shortcomings, and weaknesses. The disadvantages and advantages of RFID technology are summarised in Table 12 below.

Table 12: Advantages and disadvantages of RFID technology

Advantages of RFID	Disadvantages of RFID
• Storing unique identification data each animal in database. • Monitoring animals from birth until slaughter by unique labels/numbering system. • Tracking animal disease and easy to determine their origin. • Recording the transportation of animals, • Opportunity to follow animals without distressing them. • Allowing quick and multiple data readings. • No need to be within line of sight of the RFID reader. • RFID tags are relatively cheap.	• Short-range wireless network coverage. • Mechanical damage. • Tag collusion. • Reduction in print (circuit) quality. • Effect of static electricity. • Interference of surrounding electronic devices. • Cost implications: the need for RFID readers to be placed at various monitoring spots in the context of vast grazing lands or large farms. • Recycling burden associated with tags. • Burden of tag administration.

Source: Author`s own illustration based on Awad (2016); Stankovski et al. (2012); Voulodimos et al. (2010)

In the context of livestock identification, different forms of RFID exist. They include RFID microchip implant/injectable transponder, RFID rumen bolus, RFID ear tag, RFID collar, and chipless RFID. These are discussed and evaluated in the next sub-sections.

5.6.2.1. RFID Microchip Implant/Injectable Transponder

An RFID injectable transponder is a microchip with a unique identification. The microchip is insulated in a very small encasing glass. The microchip is placed under the animal`s skin through injection or by cutting the skin of an animal to provide individual identification. The unique identification on the microchip is read by an RFID reader and then transferred into an electronic database (Awad, 2016; Doğan et al., 2016; Finkenzeller, 2010; Want et al., 2006). Although an

RFID injectable transponder offers some degree of tamper-proof identification, but it has some disadvantages.

The disadvantage of the microchip injectable transponder is that it uses passive RFID technology with no internal battery; it relies on an external power source (Finkenzeller, 2010). If thieves know the place on the animal skin where the microchip is implanted, they can easily remove the microchip by cutting the animal`s skin. RFID implants are costly (Ekuam, 2009). Hence, the cost of an RFID implant would be a barrier to the communal farmers, and this barrier would apply in South Africa since communal livestock farmers make up the majority in South Africa. Recycling of RFID implants is a challenge. RFID implants are invasive and hurtful to the animal, and can potentially affect the animal's behaviour. Another challenge with RFID implants is that they can migrate in the animal`s body. The migration of the microchip in the animal`s body poses a threat to the meat industry, as the microchip could contaminate meat (American Veterinary Medical Foundation, 2017). Another major challenge of an RFID implant is the cost of maintenance, and lack of sustainability.

5.6.2.2. RFID Rumen Bolus

An RFID rumen bolus is a microchip that is encased in a hard ceramic casing. Each RFID rumen bolus has a unique identification number to identify each animal. The animal is made to swallow the RFID rumen bolus by inserting the microchip into the animal`s rumen using a bolus gun. The unique identification on the microchip is read by an RFID reader and then transferred into an electronic database (Doğan et al., 2016; Finkenzeller, 2010; Neil, 2014). An RFID rumen bolus offers tamper-proof identification, because it is not easy for thieves to remove the bolus. Rather, the microchip can only be recovered at slaughter (Ekuam, 2009). The major challenge with using RFID rumen bolus is the cost of the microchip. This challenge applies in South Africa since communal livestock farmers make up the majority in the country (Neil, 2014). The challenge of RFID rumen bolus is the cost of maintenance, and sustainability. In addition, recycling of RFID rumen bolus is a challenge.

5.6.2.3. RFID Ear Tag

An RFID ear tag is a microchip that uniquely identifies each animal. The technical function of an RFID ear tag is similar to that of RFID rumen bolus and RFID microchip implant transponder, but the RFID ear tag microchip is placed on the ear of animal to be identified. The unique identification on the microchip is read by an RFID reader and then transferred into an electronic database (Finkenzeller, 2010; Karmakar et al., 2013; World Bank, 2017). An RFID ear tag is the most common method of animal identification in the developed countries such as Australia and USA (MLA, 2021). An RFID ear tag suffers from some disadvantages, which could lead to several problems. Its application to the ear of the animal increases its possibility to be lost due to entanglement in bushes, trees, fences, etc. Another problem is the ease of removal of the RID ear tag. This practice is common in a society like South Africa where livestock theft is an organised crime. In case of RFID ear tag losses through accident or removal by thieves, new RFID ear tags are to be applied. This not only causes additional administrative work but also affects the welfare of the animal. The animal would have to undergo another piercing of the ear (Ekuam, 2009). In addition, recycling of RFID ear tag is a challenge.

5.6.2.4. RFID Collar

An RFID collar is a microchip that provides a unique identification code for each individual animal. While the RFID ear tag is similar to RFID rumen bolus and RFID implant, the RFID collar is placed around the neck of animal to be identified. The unique identification on the microchip is read by an RFID reader and then transferred into an electronic database (Finkenzeller, 2010; Jones & Chung, 2007). The prevalent challenge with RFID ear tags is that they do not offer a tamper-proof identification. Livestock thieves can easily remove the RFID ear tag (Ekuam, 2009). The cost of RFID ear tag would also be a barrier to the communal farmers (World Bank, 2017). The major challenge of a RFID collar is the cost of maintenance, and sustainability. Also, reuse of RFID collar is a challenge.

5.6.2.5. Chipless Radio Frequency Identification

The working principle and general architecture of a chipless RFID system is similar to that of a chipped RFID system. The chipless RFID system is comprised mainly of two components: tags and readers. The only major difference between the two systems (chipless RFID and chipped RFID) has to do with tag configuration. In a chipless RFID system, the tagging process does not involve a silicon integrated circuit (chip); the chip is replaced by printed metallic resonators. In chipless-RFID tags, the tag is equipped with a planar encoder (typically a printed pattern containing the ID code). The main driver behind chipless-RFID tags is low-cost as compared to chipped RFID tags. By using low-cost conductive inks instead of silicon integrated circuit, the price of the tagging in an RFID system can be substantially reduced. Another benefit of chipless RIFD tags over chipped RFID tags is that they are passive (do not need an embedded battery) and thus require low-power. With the developments in three-dimensional (3D) printing technology in place, this technology is suitable for the prototype fabrication and large-scale printing (mass production) of chipless RFID tags in a rapid way.

Despite the relative low-cost benefit of chipless-RFID tags over chipped RFID tags, the chipless-RFID system has some shortcomings. These shortcomings include lower sensitivity, shorter read range, lower durability, less reliability, less data capacity, and lower response time as compared to chipped RFID tags. Another drawback is that chipless RFID tags need a dedicated reader. Moreover, the chipless RFID technology is still in its infancy (Patre, 2021).

RFID tattoos is a method of animal identification, initially developed by Somark Innovations in the United States of America. RFID tattoos do not require any attachment of any object in the animal`s body. Instead a permanent biocompatible and translucent ink tattoo is applied onto the animal`s hide. The permanent ink tattoo relies on radio frequency waves to read and render unique identification numbers. The tattoo is applied using a microneedle, which is actually a geometric array of many tiny needles. One of the advantages of the RFID tattoos is low cost ink and a shorter time for ink application (Karmakar et al., 2013). Despite the low-cost advantage of RFID tattoos, chipless RFID technology has some limitations and challenges. These include: cost of RFID chipless readers; read range and speed; tag orientation on the reading process; and anti-collision, error correction and data integrity (Karmakar et al., 2013).

5.6.2.6. Summary of Electronic Identification Methods

Various forms of electronic techniques of individual livestock identification exist. They include RFID microchip implants, RFID rumen boluses, RFID ear tags, RFID ink/tattoo, neck/collars, GPS-equipped tags, and GPS-equipped neck collars. Each technique has its own advantages and disadvantages. A summary of the livestock electronic identification methods in relation to the factors outlined in section 4.3.2 is provided in Table 13 below.

Table 13: Electronic Livestock Identification Methods

	Readable at a distance	Tamper-proof	Loss-proof/Fraud-proof	Safe to the animal	Safe to the consumer of final products (e.g. meat)	Affordability to the majority of farmers	Database Compatibility	Upgradability
RFID Microchip Implants	Yes, readable with RFID reader; but short range.	No. thieves can cut out the skin and remove the chip.	No, thieves can cut out the skin and remove the chip.	No, the chip can traverse into animal body.	No, the chip can traverse into animal body and contaminate meat at slaughter.	No, costs are prohibitive.	Yes, unique numbers/symbols on the chip can be stored in central database.	Yes.
RFID Rumen Bolus	Yes, readable with RFID reader; but short range.	Yes. Difficult to remove the bolus once it is inside an animal`s rumen.	Yes. Difficult to remove the bolus once it is inside an animal`s rumen.	No. The chip can traverse into animal body.	No. The chip can create problems at slaughter, and contaminate meat.	No. Costs are prohibitive.	Yes, unique numbers/symbols on the chip can be stored in central database.	Yes, but difficult to remove the bolus once it is in the animal`s rumen.
RFID Ear Tag	Yes, readable with RFID reader; but short range.	No.	No.	Debatable.	Yes.	No. Costs are prohibitive	Yes, unique numbers/symbols on the chip can be stored in central database.	Yes.
RFID Neck/Collar	Yes, readable with RFID reader; but short range.	No.	No.	Debatable. Animal can be choked by the collar.	Yes.	No. Costs are prohibitive	Yes, unique numbers/symbols on the chip can be stored in central database.	Yes.
Photographs	No.	No.	No.	Yes.	Yes.	Yes.	Yes.	Yes.

Source: Author's illustration based on literature review

5.6.3. Biometric Livestock Identification Methods

Conventional methods such as hot iron branding can potentially affect animal behaviour or cause harm to the animal, leading to poor animal welfare. Conventional livestock identification methods can be easily manipulated, and are vulnerable to fraud, duplication, loss and alteration (Barron et al., 2009). Similarly, electronic individual livestock identification methods are not reliable; the electronic tags and collars are subject to loss, removal, and damage (Barron et al., 2009). Biometric livestock identification methods offer considerable advantages over conventional and electronic livestock identification methods. This is because the traits used to create the identification are unique and unalterable biological properties. They can offer tamper-proof, loss-proof and fraud-proof identification of livestock. They are non-invasive and not hurtful to the animal as there is no attachment of any additional element in or on the animals involved (Bugge et al, 2011; Barron et al., 2009). In the context of this research study, biometric livestock identification methods refer to DNA forensics, iris patterns, muzzle (nose) patterns, retinal patterns, visual patterns, facial recognition, visual patterns, ear vessel patterns, bite marks, saliva sampling, movement patterns and immunological labelling (Kumar, 2018; 2015; Lu et al., 2014; Jain et al., 2011; Barron et al., 2009). These biometric livestock identification methods are discussed and evaluated in the next sub-sections.

5.6.3.1. Deoxyribonucleic Acid Forensics

Deoxyribonucleic Acid (DNA) is a biological identification method that can be used to identify an individual animal with reliability. Each animal has a unique set of particular micro-satellite DNA patterns in its biological system. Deoxyribonucleic Acid investigation involves several stages and can take weeks or months to be completed. The main technologies involved in DNA sampling are mobile equipment used to collect DNA samples, and the laboratory equipment used for DNA analysis. A sample of hair, blood or meat is taken from an animal or scene in dispute, and then taken to the laboratory for analysis (Kumar, 2018; Barron et al., 2009). Worldwide, DNA forensics has been accepted as an irrefutable means of positive identification that links the animal to the lawful owner. (Zwane et al., 2013; Barron et al., 2009).

Although DNA forensic is a tamper-proof and reliable livestock identification method, it has some disadvantages. The major disadvantage of DNA forensics is that it is a long and costly process. It requires a laboratory environment and at least several hours or days or weeks or even months for completion. It involves many stages of analysis. The stages are the head of animal stage, crime scene stage, new case stage, micro-satellite DNA isolation stage, exhibits stage, analysis in the laboratory stage, DNA quantification stage, DNA amplification stage and genotyping stage (Agricultural Research Council, 2019; Barron et al., 2009). At present, there is no technology to allow for instant and automated recognition of DNA samples, therefore DNA forensics is not suitable for routine identification of livestock (Barron et al., 2009; Ekuam, 2009). Another disadvantage of DNA forensics is that it needs trained experts to accurately collect the samples and perform the analysis in the laboratory (Agricultural Research Council, 2014; Barron et al., 2009).

5.6.3.2. Iris Patterns

Iris Patterns is a biometric method of identification that involves the capturing, storing and verification of images (iris patterns) of an animal into a database. This method of identification offers tamper-proof identification. The iris patterns in the eye of animal are unique to that animal (Kumar, 2018; Barron et al., 2009; Awad, 2016; Jain et al., 2014). However, iris patterns as a method of identification has some drawbacks. One of the drawbacks is lack of visibility with the naked of the livestock stakeholders (Barron et al., 2009; Ekuam, 2009). Another disadvantage of iris patterns as a method identification is that the iris patterns in the animal`s eyes do not stabilise until the animal is several months old. Iris patterns can change following animal injury or infection (Kumar, 2018; Barron et al., 2009). Therefore, iris patterns as a method of livestock identification may not offer reliability and consistency in identifying and verifying livestock.

5.6.3.3. Retinal Patterns

Retinal patterns and iris patterns are similar methods of livestock identification. Not unlike the iris patterns in an animal`s eyes, the retinal vascular pattern is a unique and distinct biometric trait in animals (Kumar, 2018; Awad, 2016; Jain et al., 2014; Barron et al., 2009). However, retinal patterns offer some advantages over iris patterns. The major advantage of retinal patterns method is that the animal`s branching patterns of the retinal vessels, which are present from birth, do not change during the animal’s life (Kumar, 2018; Barron et al., 2009). Other advantages of retinal patterns include time and costs. Scans of retinal patterns by retinal scanners can be taken within two minutes; and is relatively inexpensive (Barron et al., 2009). A hand-held device called retinal scanner exist on the markets. The device is capable of recognising the Global Position System (GPS) coordinates. The device can be used to instantly scan, capture and record the animal`s iris patterns into a database. The retinal patterns method of identification can offer reliability, consistency, tamper-proof and accuracy when it comes to individual identification of animals (Kumar, 2018; Barron et al., 2009).

5.6.3.4. Muzzle or Nose Patterns

The muzzle or nose patterns method can be used to individually identify an animal such as cattle, sheep and goats. Muzzle patterns are unique in every individual animal. The muzzle patterns method is similar to taking finger-print identification from a human being; an ink is applied to the nose of animal and used to make nose patterns on paper. The patterns on paper are next scanned as images and then transferred into a database (QC Supply, 2022; Kumar & Singh, 2017; Barron et al., 2009). Though muzzle (nose) patterns method is simple and affordable it has some drawbacks. One of the disadvantages associated with muzzle (nose) patterns method is the possibility of inaccuracy when applying ink on the animal`s nose. This may lead to difficulty in reading the patterns (Kumar, 2018; Barron et al., 2009). There is no empirical research that shows that an animal`s muzzle (nose) prints can be stable over time (Bugge et al., 2011). Therefore, muzzle (nose) patterns may not be a reliable and consistent method of livestock identification.

5.6.3.5. Facial Recognition

Facial recognition can be used as a tamper-proof method to identify cattle, sheep and goats. One major drawback of face recognition is that an animal`s shape and face structure can change over its life time. Another major challenge with facial recognition lies with designing and developing instruments and algorithms that can perform facial recognition accurately, reliably and consistently (Barron et al., 2009).

5.6.3.6. Summary of Biometric Livestock Identification Methods

Biometric methods for individual livestock identification can be described as automated methods to accurately recognize individual animals based on distinguishing physiological or behavioural traits (Bugge et al., 2011; Jain et al., 2011; Barron et al., 2009). Various forms of biometric livestock identification exist, including Deoxyribonucleic Acid (DNA) forensics, iris patterns, muzzle (nose) patterns, retinal patterns, visual patterns, facial recognition, visual patterns, ear vessel patterns, bite marks, saliva sampling, movement patterns and immunological labelling (Kumar, 2018; Lu et al., 2014; Jain et al., 2011; Barron et al., 2009). These forms of biometric livestock identification were discussed in the previous sub-sections. Table 14 provides a summary of biometric livestock identification methods.

Table 14: Biometric methods for livestock identification

IDENTIFICATION	ADVANTAGE	DISADVANTAGE
Iris Patterns	• Patterns are unique in all individual animals. • Non-invasive - do not need to attach any additional element with or within the animals. • Suitable for routine identification of livestock.	• Lack of visibility with the naked eye. • Iris pattern does not stabilise until the animal is several months old. • Patterns may change/alter following animal injury or infection.
Muzzle (Nose) Patterns	• Patterns are unique in all individuals. • Non-invasive - do not need to attach any additional element with or within the animals. • Simple and Cheap. • Scans can be performed rapidly and images can be captured digitally into a database • Suitable for routine identification of livestock.	• Lack of visibility with the naked eye. • High possibility of inaccuracy when applying ink on the animal`s nose. • No empirical research to show that muzzle prints can be stable over time. • Not a perfectly reliable and consistent method.
Retinal Vascular Patterns	• Patterns are unique in all individual animals. • Non-invasive - do not need to attach any additional element with or within the animals. • Scans can be performed rapidly and images can be captured digitally into a database. • Animal`s retinal patterns do not change during the animal's life. • Suitable for routine identification of livestock.	• Lack of visibility through the naked eye.
Visual Patterns (e.g. colour, stripes, body structure).	• Simple and cheap. • Observations can be made at a distance. • Photographs can be taken rapidly and images can be captured digitally into a database. • Suitable for routine identification of livestock. • Non-invasive - do not need to attach any additional element with or within the animals.	• Not an ideal identifier, since two or more animals can have the exact same colour and body structure. • Animal`s appearance may change over time.
Facial Recognition	• Suitable for routine identification of livestock • Non-invasive - do not need to attach any additional element with or within the animals.	• Difficult to design instruments that can perform facial recognition accurately. • Animal shape can change over time.
DNA Analysis	• Perfect as court evidence beyond any reasonable doubt.	• Takes time to process and analyse samples in the laboratories. • Costly. • Needs experts.

IDENTIFICATION	ADVANTAGE	DISADVANTAGE
		• Lack of visibility through the naked eye. • Not suitable for routine identification of livestock.
Ear vessel patterns	• Scans can be performed rapidly and images can be captured digitally into a database. • Suitable for routine identification of livestock. • Non-invasive - do not need to attach any additional element with or within the animals.	• Hair obstruction in the animal`s ear may lead to inaccuracy and inconsistency of scans/images. • No empirical research to show that muzzle prints can be stable over time. • Not a perfectly reliable and consistent method.
Animal`s Bite marks and Saliva Sampling	• Suitable for forensic analysis.	• Not suitable for routine identification of livestock. • Not a perfectly reliable and consistent method.
Animal`s Movement patterns	• Suitable for analysis behaviour and movement of animals • Non-invasive - do not need to attach any additional element with or within the animals.	• Not suitable for routine identification of livestock. • Not a perfectly reliable and consistent method. • Costs associated with tri-axial accelerometer equipment.

Source: Author`s illustration based on literature review

5.7. Livestock Tracking: Location Tacking Technologies and Systems

In the previous section, livestock identification was discussed and various methods of livestock identification were evaluated. In addition to providing benefits for accurate record keeping and compliance with laws, livestock identification facilitates tracking of stolen, missing, stray and lost livestock. According to Krishnan et al. (2022), Cosby et al. (2021) and Ekuam (2009), livestock tracking refers to the ability to locate the whereabouts of livestock within the environment. According to Cosby et al. (2021), the location of livestock can be considered absolute or relative. Absolute location refers to specific geographic coordinates, while relative location means in relation to a known reference point of other livestock.

There are various traditional methods that can be used to track livestock, including but not limited to, fencing, manual inspection, herding, word-of-mouth, community mobilisation, and following animal footprints (Krishnan et al., 2022). Given the sophisticated and organised nature of livestock theft in South Africa, the traditional methods can be tedious, ineffective and time consuming in controlling livestock theft. The use of ICTs (location tacking technologies/systems) can facilitate smart livestock location tracking and monitoring (Krishnan et al., 2022). Real-time livestock location tracking and monitoring is made possible by technologies and systems. These technologies and systems are discussed and evaluated in section 5.8 below.

5.8. Related Research/Studies

After the literature search focusing on the two central themes and using the combinations of queries/keywords mentioned in section 5.2, the search results yielded the following various technologies and approaches:

- Radio Frequency Identification (RFID)
- Global Position System (GPS)
- Animal Biometric Technology
- Internet of Things (IoT)
- Deoxyribonucleic Acid (DNA)
- Drone Technology
- Big Data and Cloud Computing
- Machine Learning
- Virtual Fences
- ICT-based Livestock Recordkeeping Database

- Global System for Mobile Communications (GSM)
- Bluetooth
- Immersive Technologies (Virtual Reality, Augmented Reality, Mixed Reality)
- Social Media
- Remote-Activated Camera Trapping and IP Camera Surveillance of Livestock
- LPWAN Technologies

Table 15 provides a summary of the critical literature review on various technologies and approaches. That is followed by a conceptual synthesis of the technologies and approaches during which application to the South African context is considered.

Table 15: Critical literature review – summary of research on livestock identification and tracking

Technologies/Approaches	Authors	Common Theme	Gap or Weaknesses	Implications for Future Research	Implications for Practice
Radio Frequency Identification (RFID)	Akinsolu et al. (2021), Sahni & Tyagi (2016), Johnny (2015), Kim et al. (2010), Grubb (2010), Clark (2006).	Proposed solution based on RFID technology to control livestock theft.	No proposed solution for the South African context. Socio-economic and cultural factors such as farmers' language diversity, low incomes and low literary levels were not considered by majority of authors. Lack of business case studies. Lack of empirical data (e.g. interviews with stakeholders) to support the proposed solutions.	An ideal future business research would be a national or international business case or feasibility study on the benefits, disadvantages, costs, and risks of a RFID national comprehensive system.	Individual and unique identification of livestock is possible with RFID. RFID facilitate automated data entry, retrieval and reporting.
	Ismail & Ismail (2016), Doğan et al. (2016), Ruiz-Garcia & Lunadei (2011), Suh et al. (2013), Siror et al. (2009, Pongpaibool (2008) and Jinaporn et al. (2008), Suh et al. (2013), Moreki & Ntesang (2012).	Review of RFID technology to control livestock theft.	Lack of review studies on integrating RFID with modern technologies.	An ideal future would be reviewing the possibilities of integrating RFID with 4IR technologies.	RFID rumen bolus has high retention rate, greater security, and is tamper-proof compared to RFID ear tags. RFID tags are often considered the most widely adopted livestock identification method due to their low cost compared RFID boluses. The key shortcoming is that RFID ear tags can be easily removed, lost or tampered with.
	Vlad et al. (2012), Bowling et al. (2008), Moreki & Ntesang (2012).	Evaluation of the livestock identification systems implemented in the selected countries.	National RFID livestock information system does not exist in South Africa. Animal welfare issues were not discussed.	An ideal future research could focus on an empirical investigation an association/correlation between animal welfare and RFID.	RFID suffers from system errors, omissions and anomalies, data quality challenges, data inconsistencies, stakeholder communication

Technologies/Approaches	Authors	Common Theme	Gap or Weaknesses	Implications for Future Research	Implications for Practice
					challenges, and costs of maintaining the system.
Global Position System (GPS) tracker devices	Zantsi & Nkunjana (2021), Maluleke (2017), Kubasu & Wachira (2010).	Likelihood to adopt GPS tracker devices by the African smallholder livestock farmers to control livestock theft.	Very few studies have made a case for using this technology in curbing stock theft among communal livestock farmers and smallholder livestock farmers.	An ideal future research would be a compressive and national study to determine/measure farmers` readiness to adopt GPS trackers.	The adoption of GPS trackers would depend on factors such farmers' awareness of GPS trackers, access to GPS trackers, income, risk behavior, and culture.
	Chikwuma & Francis (2014), Scheepers et al. 2017), Nkwari et al. (2014), Clark (2006), Johnny (2015), Kim et al. (2010), Siror et at (2009).	Proposed solution based on GPS technology to control livestock theft.	No proposed solution for the South African context. Socio-economic and cultural factors such as farmers' language diversity, low incomes and low literary levels were not considered by majority of authors. Lack of business case studies. Lack of empirical data (e.g. interviews with stakeholders) to support the proposed solutions.	An ideal future business research would be a national or international business case or feasibility study on the benefits, disadvantages, costs, and risks of a GPS trackers national comprehensive system.	Considering the income levels of African communal livestock farmers, GPS tracker devices are expensive. The key shortcoming is that GPS tracker devices can be easily removed, lost or tampered with.
Animal Biometric Technology	Kumar & Singh (2020).	Review of animal biometric technology.		An ideal future research would be reviewing the possibilities of integrating animal biometric technology with 4IR technologies.	Retinal pattern-based animal biometric systems can be widely deployed across an extensive variety of individual animals like cattle, sheep and goats.
	Ali Shojaeipour et al. (2021), Kumar & Singh (2016), Noviyanto & Arymurthy (2012), Barry et al. (2007), Minagawa et al. (2002), Kim et al. (2005), Cai & Li (2013),	Empirical testing of animal biometric identification methods.	Lack of business case studies. No proposed solution for the South African context.	To fill this gap, a retinal-based biometric system to control livestock theft in the country has been proposed and illustrated in this research study.	Animal biometrics can be used as a tamper-proof and durable technique in ensuring effective identification and traceability/tracking of animals.

Technologies/Approaches	Authors	Common Theme	Gap or Weaknesses	Implications for Future Research	Implications for Practice
	Awad et al. (2013), Corkery et al. (2007), Zhao et al. (2019), Corkery et al. (2007), Allen, et al. (2007), Barron et al. (2008), Barry et al. (2011).				
Internet of Things (IoT).	Farooq et al. (2022) and Akhigbe et al. (2021) role of IoT in the livestock.	Review of the role of IoT in livestock management	Lack of business case studies.	An ideal future research would be focusing on examining an existing use case of G5 network integrated with IoT, cloud computing, big data, and artificial intelligence for smart livestock farming.	The main issue would be tampering with and removal of IoT animal devices by the livestock theft perpetrators, given the sophisticated tactics of livestock theft perpetrators.
	Imtihan et al. (2021), Joshitha et al. (2021), Priyanka (2019), Joshitha et al (2021), Ojo et al. (2021), Stojkoska et al. (2018), Gbemisola et al. (2018), Stojkoska et al. (2018), Saravanan & Saraniya (2018), Abdullahi et al. (2019), Dieng et al. (2017), Wamuyu (2017).	Proposed solution based on IoT to control livestock theft.	Lack of farming community pilot projects on IoT to control livestock theft. No proposed solution for the South African context. Socio-economic and cultural factors such as farmers' language diversity, low incomes and low literary levels were not considered by majority of authors. Lack of business case studies. Lack of empirical data (e.g. interviews with stakeholders) to support the proposed solutions.	An ideal future would be a business case or feasibility study on the benefits, disadvantages, costs, and risks of an IoT based system for a specific local community. An ideal future would be investigating the country`s state of IoT readiness for livestock farming.	High implementation costs due to the need to deploy many IoT animal devices and IoT gateways. Pilot projects can be undertaken within a particular local community to ascertain the impact, adopt, and benefits of IoT.
	Maluleke (2018)	Integration of conventional methods and various IoTs to control livestock theft.	Proposed suggestion was not supported by empirical data (e.g. interviews with key	An ideal future research would be investigating the farmer`s readiness and relevant	Implementation costs would be very high.

Technologies/Approaches	Authors	Common Theme	Gap or Weaknesses	Implications for Future Research	Implications for Practice
			industry stakeholders) nor business case.	stakeholders to use such various IoTs livestock management.	
	Maluleke (2021), Maluleke (2018) Hofmeyr (2018)	Stakeholders` experiences on the subject of DNA in combating stock theft.	Lack of data on the number livestock theft cases resolved through DNA.	An ideal future research would be investigating the livestock theft cases that were resolved through DNA forensics.	DNA is an irrefutable means of identification of an individual, and can be used to trace the lawful owner of an animal in the presence of a reference sample. However, DNA forensics is not suitable for routine livestock and tracking.
	Zwane et al. (2013)	A review of forensic DNA technology to control livestock theft.	Lack of data on the number of livestock theft cases resolved through DNA application.	An ideal future research would be investigating the livestock theft cases that were resolved through DNA forensics.	The biggest constraint to a full large-scale implementation of the technique is the high costs related to the high-tech equipment that is necessary.
Drones	Greenwood (2016), Haevic Team (2015), Airborne Drones (2015) and Miles (2014), Airborne Drones (2015).	Insights on the role, benefits and challenges of drones to control livestock theft.			Drones can be fitted with various sensors to enhance livestock identification and tracking, machine learning, big data, and analytics.
	Van Rooyen (2016), Van Rooyen (2017) and Du Pisanie (2018), Du Pisanie (2018), Maluleke (2020), Soesilo and Rambaldi (2018)	The South African drone industry. An exploration of the use of drones in the context of controlling of livestock theft.	Despite South Africa being the largest drone market in Africa, there is a lack of drone business cases in the context controlling livestock theft.		Accessibility of drone by communal farmers remains a challenge due to high costs and complexity of drones.
	Vayssade et al. (2019)	Proposed solution based on drone technology to control livestock theft.	No proposed solution for the South African context. Socio-economic	To fill this gap, drone technology integrated with cloud services to	There is a general consensus among ICTs informants that drones

Technologies/Approaches	Authors	Common Theme	Gap or Weaknesses	Implications for Future Research	Implications for Practice
			and cultural factors such as farmers' language diversity, low incomes and low literary levels were not considered by majority of authors. Lack of business case studies. Lack of empirical data (e.g. interviews with stakeholders) to support the proposed solutions.	control livestock theft in the country has been proposed in this research study.	can play a big role in livestock identification and tracking. In terms of implementation, drone technology offers low costs compared to deploying GPS tracker devices and IoT devices.
	Swain et al. (2018) Kobler (2012).	Description of a use case of drone technology in the context of controlling of livestock theft.	Lack of use cases in Africa.	An ideal future research would be an empirical study of drone use cases in Africa.	Drone evidence can be used for the prosecution of livestock theft perpetrators, in addition to livestock identification, tracking, counting, monitoring, etc.
Big Data and Cloud Computing	Akhigbe et al. (2021)	A review of trends on big data, cloud computing and IoT for livestock management.	Lack of data about Africa. Trends in Africa are under researched.	An ideal future review could focus on the African continent. An ideal future research would be investing the country`s institution (e.g. Police, Military, etc) readiness to deploy, implement and adopt advanced technologies such as HunchLab.	Geographic prediction tools such as HunchLab can be used to predict livestock theft risks in specific locations. Integrated predictive analytics tools such as IBM i2 Coplink can be used to consolidate disparate data sets (such as arrest records, mugshots, location data and known gang affiliations) into a single dashboard, from which police across different locations can view and share vital information.

Technologies/Approaches	Authors	Common Theme	Gap or Weaknesses	Implications for Future Research	Implications for Practice
	Clark (2017).	Role of big data in crime prevention.	Lack of data about Africa. Trends in Africa are under researched.	An ideal future research would be investing the country`s institution (e.g. Police, Intelligence etc) readiness to deploy, implement and adopt advanced technologies such as Watson Analytics for crime prevention.	Tools such as Watson Analytics for Social Media Social Media can be used to analyse the social sentiment of user-generated content, identifying possible signs of livestock theft and flagging suspicious posts for further review.
Machine Learning	Garcia et al. (2020), Sharma et al. (2020), Kleanthous et al. (2022).	A review of machine learning in precision livestock farming.	Lack of literature data about South Africa.	An ideal future research would be a business case or feasibility study on machine learning models for the South African context.	Machine learning requires large datasets (big data) and cloud-based storage. Official reported cases of livestock theft to the SAPS, unofficial reported cases of livestock theft, stray livestock, livestock kept at animal pounds, and suspicious posts on social media can all form part of large datasets (big data).
	Katamba (2019)	Description of a use case of machine learning in the context of controlling of livestock theft	Lack of use case in South Africa. Lack of machine learning research in Africa.	An ideal future research would be developing a machine learning model that can learn from SAPS`s livestock theft cases, social media data and other big data to predict possible livestock theft hotspots	The availability of open source machine learning platforms such as Tensor Flow algorithms offers low cost.
	Aquilani et al. (2022).	A review of virtual fencing in the context of precision livestock farming.	Lack of use case in South Africa. Lack of virtual fence research in Africa.	An ideal future research would be exploring an investment (costs, risks, benefits, value	Most virtual fences and their associated mobile apps rely on GPS tracker devices and GSM

Technologies/Approaches	Authors	Common Theme	Gap or Weaknesses	Implications for Future Research	Implications for Practice
Virtual Fences				proposition, etc.) of virtual fences from the selected South African large-scale livestock commercial farmers.	devices; of which GPS tracker devices are expensive in principle.
	Acosta et al. (2020), Sattarov et al. (2019), Tangorra et al. (2013)	Proposed virtual fence system to control livestock theft.	No proposed solution for the South African context.	An ideal future research would be implementing, testing and evaluating a virtual fence in a South African commercial farming community where livestock can be confined within the farm boundaries.	In the rural and communal livestock sector, livestock grazing is not limited to a specific rural community – this can make it difficult to implement virtual fences in the rural and communal context.
ICT-based Livestock Recordkeeping Database	Odendaal (2020), ÇELİKYÜREK et al. (2019).	Description of database application, and the importance of database in livestock farming.	South African has more than 30 million livestock (cattle, sheep and goats combined) – a holistic/comprehensive perspective of a national livestock population has not been explored.	An ideal future research could focus on reviewing and evaluating the national livestock databases implemented in the developing countries.	A national livestock database can facilitate the control of livestock theft, diseases and movement in the country.
	Molotsi and Makombe (2019).	The design of a web-application recordkeeping database for livestock records.	The databased designed has some limitations such as issues with individual and unique identification livestock and manual data entry.	To fill this gap, a national (South African context) livestock database has been illustrated in this research study.	Every animal can have its unique digital identify throughout its lifetime. The unique identity can be linked to various aspects such as owner, farming community, farmstead, region, province, etc. With modern ICTs, it is possible to automate data entry, search and retrieval.
	Kriel (2020), Katamba & Mutebi (2017).	Description of mobile apps designed for controlling livestock theft.	No empirical data on the use/adoption and impact of these apps. The apps	To fill this gap, a mobile crowdsourcing approach targeted at multiple	The mobile apps rely on data from GPS tracker devices and embedded

Technologies/Approaches	Authors	Common Theme	Gap or Weaknesses	Implications for Future Research	Implications for Practice
Global System for Mobile Communications (GSM)			are targeted at commercial farmers. Lack of applications suitable for low-income, rural and communal farmers.	stakeholders including rural and communal farmers to control livestock theft in the country has been proposed in this research study.	GSM/IoT devices attached to animals. GPS tracker devices and embedded GSM/IoT devices are expensive.
	Sirotek & Hart (2019).	Field testing of GSM for location of livestock.			GSM is not recommended for real-time location tracking, rather it is recommended for data transfer. GPS is recommended for real-time location tracking.
	Lemma et al. (2019a).	Proposed system based on GSM-GPS enabled devices to control livestock theft.	No proposed solution for the South African context.		GPS tracker devices and embedded GSM devices attached to animals are expensive.
Bluetooth	Makario & Maina (2021), Maroto-Molina et al. (2019.	Bluetooth Low Energy (BLE) based system for livestock identification, tracking, counting and localization in the farm.	No proposed solution for the South African context.		Not an ideal tracking solution for large grazing mode in the rural and communal livestock sector due to short-range coverage.
Immersive Technologies (Virtual Reality, Augmented Reality, Mixed Reality)	Caria et al. (2020), Caira et al. (2019), Zhao et al. (2017), Simon & Prasad (2017).	Proposed solution for identifying and locating livestock.	Limited data on AR/VR fieldwork experiments/tests. No proposed solutions for the African context. Lack of use cases, even among the large-scale commercial livestock farmers.	An ideal research could focus on the awareness and potential benefits of immersive technologies among large-scale farmers.	Lack of AR or VR commercial products specifically available for the livestock farming sector. AR gadgets and VR gadgets are expensive. The use efficient use of immersive technologies needs data from sensors such as GPS trackers, IoT devices, and these devices are expensive.

Technologies/Approaches	Authors	Common Theme	Gap or Weaknesses	Implications for Future Research	Implications for Practice
Social Media and Instant Messaging	Nunns et al. (2022) Cognac (2018), Clack (2015).	The role of social media instant messaging in crime prevention and against livestock theft.	The concept of crowdsourcing for controlling livestock is under researched.	To fill-in this gap, a crowdsourcing approach to control livestock theft in the country has been proposed and illustrated in this research study.	With the developments in web 2.0, mobile phone technology and 4IR technologies, the low-cost implementation of the concept of crowdsourcing for controlling theft can be possible.

Source: Author`s own illustration based on the citations listed in the second column.

Section 5.8 further analyse pertinent technologies and approaches towards developing a model for a livestock identification and tracking system. The last paragraph in each sub-section provides the implications of the synthesised related research to the South African socio-economic, technological, environmental and cultural context.

5.8.1. Radio Frequency Identification (RFID) Technology

To mitigate livestock rustling and the illegal sales of stolen livestock, Akinsolu et al. (2021) proposes design considerations and data communication architecture for national animal identification and traceability system in Nigeria. The architecture is made of three components: RFID tags, RFID readers, and 5G module. The proposed architecture has some weaknesses. Firstly, the users of the system have been not identified. Secondly, the security measures of RFID tags have not been explained – as tags are prone to loss, damage, and fraud. Similar proposed solutions were found in other research studies. Likewise, Sahni & Tyagi (2016) presented a solution based on RFID technology, to mitigate cattle rustling in India. The major components of the presented solution include passive Low Frequency RFID tag (ear tag), RFID reader, RFID middleware, centralised database, and GSM module. Similar proposals were provided by Johnny (2015), Kim et al. (2010), Grubb (2010), and Clark (2006).

Awad (2016) conducted a literature survey on the evolution of cattle identification and tracking methods. He concluded that: (i) classical methods do not cope with the current cattle identification requirements; (ii) RFID has gained popularity in cattle identification, but with security issues; (iii) animal biometrics is a promising technology, but with accuracy issues; and (iv) studies on integrating animal biometrics into RFID are encouraged. Similarly, Doğan et al. (2016) reviewed the use of RFID systems on animal monitoring. They concluded that although RFID tags in animal tracking and monitoring are widely used in countries like Australia, USA, Japan, and South Korea, RFID systems have some challenges. These challenges include high costs of RFID systems, difficulties of use of RFID tags, and weaknesses of RFID tags. The tags are open to outside interference (strike, theft, replacement, etc.). Moreover, injectable RFID tags may merge into food when the animal is slaughtered. Ruiz-Garcia & Lunadei (2011) carried out a similar study and obtained similar findings. He found that implementing an RFID system involves a multitude of challenges such as extreme temperatures, huge volume of data that are difficult to manage, and the need of longer reading ranges.

Vlad et al. (2012) evaluated the livestock identification systems implemented in Australia, Britain, EU and USA. The systems implemented in Australia, Britain, EU and USA all use RFID technology as a method of livestock identification. They found that the Australian livestock identification system had been well accepted by the Australian stakeholders. In contrast, the livestock identification system implemented in Britain, EU and USA had some problems. These include system errors, omissions and anomalies, data quality challenges, data inconsistencies, stakeholder communication challenges, and costs of maintaining the system. Studies similar to the study conducted by Vlad et al. (2012) were conducted by Bowling et al. (2008). Similar findings were obtained. Moreki & Ntesang (2012) provided information on cattle identification and traceability in Botswana. Those scholars found that Botswana relied on four methods of cattle identification. The methods are ear notching, hot iron branding, conventional plastic ear tags and RFID rumen bolus, and the methods were used simultaneously. The RFID rumen bolus experienced challenges and was later replaced with RIFD ear tags. The RFID ear tags were well accepted by the Botswana farmers due to extensive government support and subsidy scheme.

Suh et al. (2013) reports that RFID tags are often considered the most widely adopted livestock identification method due to their low cost compared RFID boluses. Ekuam (2009), Siror et al. (2009, Pongpaibool (2008) and Jinaporn et al. (2008) concur with Suh et al. (2013). They all agree that RFID technology can offer a solution for tracking, identifying and recovering stolen livestock; and combating livestock theft. However, RFID rumen bolus has high retention rate, greater security, and is tamper-proof compared to RFID ear tags. The key shortcoming is that RFID ear tags can be easily removed, lost or tampered with (Moreki & Ntesang, 2012).

There are a number of implications for the South African context regarding rural areas, communal grazing areas, organised crime and other matters as indicated below.

- **Rural Areas:** Most encountered research studies did not consider the context, factors, constraints and challenges of livestock communal farmers. The South African livestock farming is largely concentrated among communal farmers in the rural areas. For, instance Grubb (2010) proposed a web-based system that does not consider the context of rural communities; considering the fact that in Africa the vast majority of the population are using mobile phones. The studies did not consider the organised nature and dynamics of livestock theft.
- **Large and shared communal grazing areas**: In communal farming, the livestock farming sector is mostly based on grazing mode. In rural areas, the grazing areas are often very large. It is impractical to utilise the RFID technology to identify and track/locate livestock when grazing over a large span of areas. In terms of geographic coverage, RFID technology has a short range.
- **Livestock theft is an organised crime:** In South Africa, livestock theft is an organised crime that involves syndicates. RFID ear tags do not offer a tamper-proof identification; thieves can easily remove them, or alter them before selling the stolen livestock, without farmers' awareness.

- **The number of RFID devices to be deployed:** The number of tags, collars, boluses, or implants is related to cost, which is a very important issue in rural context. In South Africa, livestock farming is predominant in the rural areas, and farmers generally have many herds of animals. Issues such as administering, maintaining, recycling and discarding these devices needs to be considered.
- **Animal Welfare:** None of the research studies that proposed RFID solutions considered the animal welfare issues.
- **Social-cultural issues:** Most of the research studies did not consider the national cultural consideration, for example, language barrier. For example, South Africa has eleven official languages.
- **Cross-border issue:** In South Africa, livestock theft involves smuggling livestock into neighbouring countries such as Botswana and Swaziland. None of the related research studies considered cross-border theft.
- **Holistic approach:** Most the research studies focused only on farmers as the end-user of their proposed solutions. They did not consider other relevant stakeholders such as the police, traditional authority, stock theft preventative form, and industry organisations. In Chapter One, livestock theft is highlighted as a complex phenomenon that needs a close and concerted partnership-based collaboration, interaction and information exchange.
- **Lack of business cases (use cases):** No business case of RFID technology among communal farmers in South Africa was found in the literature. There is a lack of empirical research on the adoption of RFID technology by South African livestock farmers.

5.8.2. Global Position System (GPS) Devices

Global Navigation Satellite System (GNSS) is one of the essential elements of the global network infrastructure. People, livestock, wild animals and objects can be tracked to their exact geographic location using GNSS related technologies. There are four major GNSSs in use today; they include the American Global Positioning System (GPS), Russian GLONASS, European Galileo and the Chinese BeiDou. The GNSS is used to determine the position and track the parameters of movement of animals and objects (GPS.Gov, 2022). It provides users (anywhere on earth) with positioning, navigation, and timing services. The GPS consists of space segment (orbiting satellites), control segment (tracks and monitors orbiting satellites) and user segment (GPS receiver device). The GPS services (position, navigation and timing) are free and open for use to anyone worldwide. The GPS is the most widely used localization system used for outdoor localization purposes, such as locating and tracking livestock, cars, and assets, among others (Ojo et al., 2022). The technology has been used in agriculture to track animals, particularly endangered wildlife species such as rhinos and elephants in South Africa (Wildlife ACT, 2014).

Global Position System has been adopted in various sectors including the transport, government, and agricultural sectors in South Africa. A research study conducted by Jere and Ndayizigamiy (2018) determined that the Department of Agriculture was piloting the implementation of devices known as digital pens that use GPS coordinates to track farm visits by extension officers. The research study found out that about 52% of the extension officers were using the devices on farm visits. The residents of Gauteng Province are using a safety and security mobile application known as Namola. The Namola mobile application uses GPS co-ordinates to map locations in partnership with the Gauteng traffic police control room. The app helps the Gauteng residents receive emergency response from the police (Dial Direct, 2017). Another example of GPS use in South Africa is that of wildlife tracking and monitoring by an organization called Wildlife Act. That organization uses GPS technology for keeping track of animal movement patterns, habitat utilization, population demographics, snaring and poaching incidents and breakouts (Wildlife Act, 2017). The literature did not disclose the adoption and use of GPS tracking among communal farmers for technology aimed at livestock identification and tracking in South Africa.

Recently, there has been a rapid development in GPS tracking devices. In the context of livestock identification and tracking, a GPS tracking device refers to a GPS quipped electronic device meant to be attached to an animal's ear or neck. The device communicates with GNSS to get its geographic coordinates and its location/position on earth. Most of the companies that have developed GPS livestock tracking devices are found in North America and Europe. For instance, Digital Matter is a USA based company that offers a variety of battery-powered tracking devices for livestock. The devices are GPS equipped, IoT equipped, Bluetooth equipped and GSM equipped. The company claims that their tracking devices have features such as global connectivity, lightweight, off the shelf batteries, theft recovery, advanced geofencing, ease of installation, flexible configuration, two-year manufacturer's warranty, inactivity detection, sleep mode, and rugged and weatherproof (Digital Matter, 2022). Another company by the name of Smarter Technologies with its headquarters in United Kingdom (UK) offers the same devices with the same features (Smarter Technologies, 2022).

Animals` locations can be stored on the GPS collar device or into a centralised database. The major advantage of GPS-equipped collar devices is that data about animals` location can be collected anywhere on the planet earth, any time of the day or night remotely and regularly

(Emsilie, 2014; Ekuam, 2009). The major disadvantage of GPS-equipped collar device is that they need constant battery power to function, and the life span of the battery is very short. Another major disadvantage GPS-equipped collar device is that they are very expensive. For instance, one package of GPS-equipped collar device for one animal costs about R15 000 – R50 000 (Emsilie, 2014).

Zantsi & Nkunjana (2021) conducted a review of the likelihood that smallholder livestock farmers in South Africa adopt GPS animal tracking devices to mitigate the impact of livestock theft. Maluleke (2017) conducted a similar study in the South African context; while Kubasu & Wachira (2010) conducted a similar study in Kenya. These three studies share similar highlights. The first major highlight is that many studies indicate that numerous brands of the GPS animal tracking devices have been designed and tested for commercial purposes in Africa. Secondly, very few studies have made a case for using this technology in curbing livestock theft among communal livestock farmers and smallholder livestock farmers. Thirdly, considering the South African socio-economic, cultural and technological context, the likelihood of GPS animal tracking device adoption by communal livestock farmers and smallholder livestock farmers would depend on: (i) the awareness about the devices and how they work; (ii) the acuteness of livestock theft for a farmer and how livestock contributes the farmer's livelihood; and (iii) the income level, access to mobile phones and risk behaviour of farmers.

Various authors have proposed systems based on GPS technology to mitigate livestock theft. Chikwuma & Francis (2014) developed cattle monitoring system for tracking cattle combating rustling in extensive grazing areas, grazing reserves, grazing routes and ranches. The system is mainly made up of a collar that consists majorly of GSM and GPS modules. The system sends an SMS containing the coordinates of the collar to the farmer, enabling the farmer to check the cattle's position. Also, the system sends an SMS to alert the farmer when the device`s battery power runs low. Francis et al. (2018) and Tangorro et al. (2013) proposed a similar system. Scholars such as Stojkoska et al. (2018), Nkwari et al. (2014) and Clark (2006) developed a similar system based on their respective studies. However, the system developed by Scheepers et al. (2014) has a solar panel to recharge the battery of a GPS module device. The system created by Nkwari et al. (2014) is based on GPS devices. Finally, Clark's (2006) system uses both memory-card built-on GPS tracking collar to store data, and a hand-held mobile base station embedded with pocket-PC Personal Digital Assistant (PDA).

The proposed systems have some limitations and shortcomings. One of the major shortcomings is the cost of GPS tracking collars. For instance, in 2021, the price of a GPS tracker device was R2200 per animal excluding VAT (Farm Ranger, 2021). Costs would be a barrier to the communal farmers, smallholder farmer, and emerging farmers. The proposed system uses a memory-card built-on GPS tracking collar to store data, instead of storing data into a centralised or distributed database. An issue is that livestock thieves can easily remove a GPS tracking collar. Considering animal welfare and wandering-around behaviour of animals, a collar device that is composed of GSM module, GPS module, battery and solar panel may be heavy to an animal and pose a physiological risk to the animal. The limitation of the system proposed by Nkwari et al. (2014) is that it was tested only on one cow.

Johnny (2015) took a slightly different approach as compared to Chikwuma & Francis (2014), Stojkoska et al. (2018), and Nkwari et al. (2014). His proposed system consists of (i) an implant GPS receiver that is inserted into an animal`s body; (ii) the GPS system that communicates with an implant GPS receiver; (iii) a remote database server that stores animal`s position and animal`s medical history; (iv) wireless computing devices such as tablet computer, smartphones; a network (cellular network or satellite based Internet); and (v) a software application installed on a wireless computing device. The system proposed by Johnny (2015) is a novel concept for tracking the whereabouts of animals and offering a tamper-proof solution. However, an implant GPS receiver would be expensive for communal farmers and smallholder famers, who comprise the majority of farmers in South Africa. Secondly, an implant GPS receiver would pose recycling burdens. Thirdly, an implant GPS receiver poses animal welfare and health concerns such as the implant GPS receiver migrating into animal`s body and contaminating meat.

The proposal by Kim et al. (2010) is different from all the above proposals in the sense that their architecture is an integration of RFID technology, GPS technology, and sensors. The major shortcoming of their architecture is that their system is based on an outdated database system (Windows Server 2003 and MS-SQL2000 DBMS) and outdated client operating system (Windows XP). Siror et al. (2009) proposed a similar system based on RFID technology and GPS technology to combat cattle rustling in the East Africa. Although the proposed system by Siror et al (2009) is directly aimed at addressing livestock, the system has some shortcomings. Firstly, a neck collar integrated GPS receiver can be easily removed by thieves before they steal the animal. Secondly, the link between the RFID bolus and neck collar integrated GPS receiver has not been described. Thirdly, the system needs an installation of various outdoor readers; this would be a major challenge, burden and cost in the communal livestock sector as vast tracts of grazing lands are shared by communities.

The GPS devices present a number of implications for the South African context. The implications are explained below.

- **GNSS Network:** GPS is a global network, available day and night. GPS is considered as the accurate localization technology. South African is widely covered by the GPS network.
- **Costs of GPS tracking devices:** The major issue with GPS tracking devices is high cost. South African livestock communal farmers, substance farmers, small farmers are characterised by low incomes.
- **Tamper-proof:** GPS tracking devices do not offer a tamper-proof and permanent solution, thieves can remove them. Livestock theft in South Africa is an organised crime that involves syndicate networks.
- **Battery Lifespan:** One of the drawbacks of GPS devices is power consumption and battery life span.
- **Market for GPS technology:** GPS livestock tracking devices such as collars and tags are available on the South African market. Some companies that offer these devices include Agri-Smart and AgriMag.
- **Cross-border issue:** Stolen livestock are smuggled into neighbouring countries. Since GPS is a global network, the technology can be advantageous in tracking livestock around the borders.
- **Animal Welfare:** GPS tracking devices embedded with batteries, solar panels and other electronics can be relatively heavy and cause strain to the animal.
- **Lack of business cases (use cases):** No business case of GPS tracking devices among communal farmers in South Africa was found in the literature. There is a lack of empirical research on the adoption of GPS tracking devices by South African livestock farmers.

5.8.3. Animal Biometric Technology

Kumar & Singh (2020) provided a comprehensive review of animal recognition and tracking biometric systems. Their review focused on these animal biometric feature characteristics: Retinal Patterns, Muzzle Point Image Patterns, DNA-Based Animal Identification, Iris Biometric-Based Animal Identification. In their review, Kumar & Singh (2020) identified major benefits, opportunities and challenges of each animal biometric identification method. The identification method of retinal patterns is found in almost all individual animals including cattle, sheep and goats across the world. The major drawback of retinal patterns is that an animal can suffer from injuries to the cornea of its eyes, thus making it difficult to acquire and extract accurate feature samples. The major benefit of iris patterns is that it is unique in every animal and immutable identifier to identify the individual animal. Several research studies have confirmed that muzzle point image pattern of cattle is also a unique biometric feature for recognition of individual animals. No research study has confirmed that muzzle point image patterns of sheep and goats are unique biometric features in every animal. Nose problems and injury marks on the surface of nose of animal can be a challenge in acquiring and extracting accurate feature samples of muzzle patterns.

Kumar & Singh (2020) recommend that retinal pattern-based animal biometric systems be widely deployed across an extensive variety of individual animals like cattle, sheep and goats. The identified challenges associated with recognition and tracking animal biometric systems include the acquisition of suitable biometric identifiers, recognition rate, computation time, and overall system operability. Kumar & Singh (2020) point out that the major issue with animal recognition and tracking animal biometric systems is that there is no publicly available animal biometric characteristics-based database for the animal recognition. There is no animal biometric database system that can be used to estimate the current state-of-the-art recognition systems, test exiting algorithms and develop new algorithms. Also, across the world there is a lack of business cases on animal recognition and tracking animal biometric systems, and this has contributed to limited empirical research.

In Australia, Shojaeipour et al. (2021) collected 300 biometric images consisting of the cattle muzzle and face from 300 mixed cattle. They used the 300 images to develop the YOLO-ResNet-50 muzzle biometric identification system, a deep learning modelling approach for the identification of individual cattle. The results of their algorithm yielded 99.13% of muzzle detection accuracy and the overall biometric identification achieved 99.11% testing accuracy. Similarly, Kumar & Singh (2016) also focused their research study on muzzle patterns. They proposed a hybrid feature extraction approach for the automatic recognition and classification of cattle breeds based on captured muzzle point image pattern features using a low-cost camera. They used 5000 images of muzzle image patterns of cattle as a representative sample. Their proposed approach yielded the recognition accuracies of 94.5%. They concluded that their proposed approach can provide better solutions to problems of cattle identification, registration, recognition and traceability. Noviyanto & Arymurthy (2013), Barry et al. (2007), Cai & Li (2013), Awad et al. (2013) and Corkery et al. (2007) conducted similar research studies.

Zhao et al. (2019) took a different approach; their research study focused on body images of cows. Instead of YOLO algorithm, they tested five algorithms, namely: Features from Accelerated Segment Test (FAST), Scale Invariant Feature Transformation (SIFT), Fast Library for Approximate Nearest Neighbour (FLANN), Oriented FAST and Rotated BRIEF (ORB) and Brute Force (BF). In their research study, a vision system is proposed to extract body images and identify Holstein cows. They collected sample data (video images) from 66 cows. The results of their proposed system showed that the identification accuracies of SIFT and SURF were 91.39% and 91.46%, respectively, while the detection efficiency of SURF was higher than that of SIFT. ORB had the highest identification accuracy and efficiency. The overall detection accuracy of the proposed system was 95.41%. Another research study based on animal visual patterns was carried out by Corkery et al. (2007) in the USA. They focused on face recognition as a biometric-based identifier for sheep. In their research study, an algorithm training was performed independently on several normalized face images from 50 sheep (sets of two, three, and four training images per sheep). The results of their algorithm obtained a recognition rate of 96%.

In Ireland, Allen, et al. (2008) focused on retinal patterns. In their research study, they selected 869 cattle for retinal identification imaging – to create 1738 retinal patterns. The research results indicated that none of the comparisons yielded an identical retinal pattern; meaning that each retinal pattern was unique within the dataset. They then concluded that an animal biometric identification system could be deployed as a stand-alone system for animal identity verification. Or it could be deployed along with ear-tag-based identification system in support of identification, registration and movement of animals. Similarly, Barron et al. (2008) conducted a research by assessing the retinal recognition technology as a biometric method for sheep identification. The results of their research revealed that recognition errors of the one-retina biometric system were estimated to be 0.25% for false matches and 0.82% for false non-matches. They suggested that animal biometric can be used as a tamper-proof and durable technique in ensuring effective identification and traceability of animals. Barry et al. (2011) carried out research on the verification of sheep identity by means of a retinal recognition system. In their research they used 160 sheep as a representative sample; and they obtained similar results as Barron (2008).

The animal biometric technology presents a number of implications for the South African context. The implications are explained below.

- **Cost Factor:** Biometric identification is relatively more cost-effective than RFID devices, GPS devices, IoT/sensor devices; considering that a biometric identification system does not require an attachment of electronic devices on the animal.
- **Tamper-proof:** Biometric identification cannot be forged and altered; it is a unique and permanent identification.

- **Animal welfare:** A biometric identification system does not require an attachment of technological devices on the animal, therefore does not pose strains on the animals.
- **Lack of business cases (use cases):** No business case of biometric technology among livestock farmers in South Africa was found in the literature. There is a lack of empirical research on the adoption of biometric technology by South African livestock farmers.

5.8.4. Internet of Things (IoT)

Farooq et al. (2022), Akhigbe et al. (2021) and Vigneswari (2021) presented a comprehensive literature survey on the role of IoT in the livestock sector by categorizing and synthesizing existing research work in this area. The contribution of Farooq et al. (2022) is illustrated in figure 6 below.

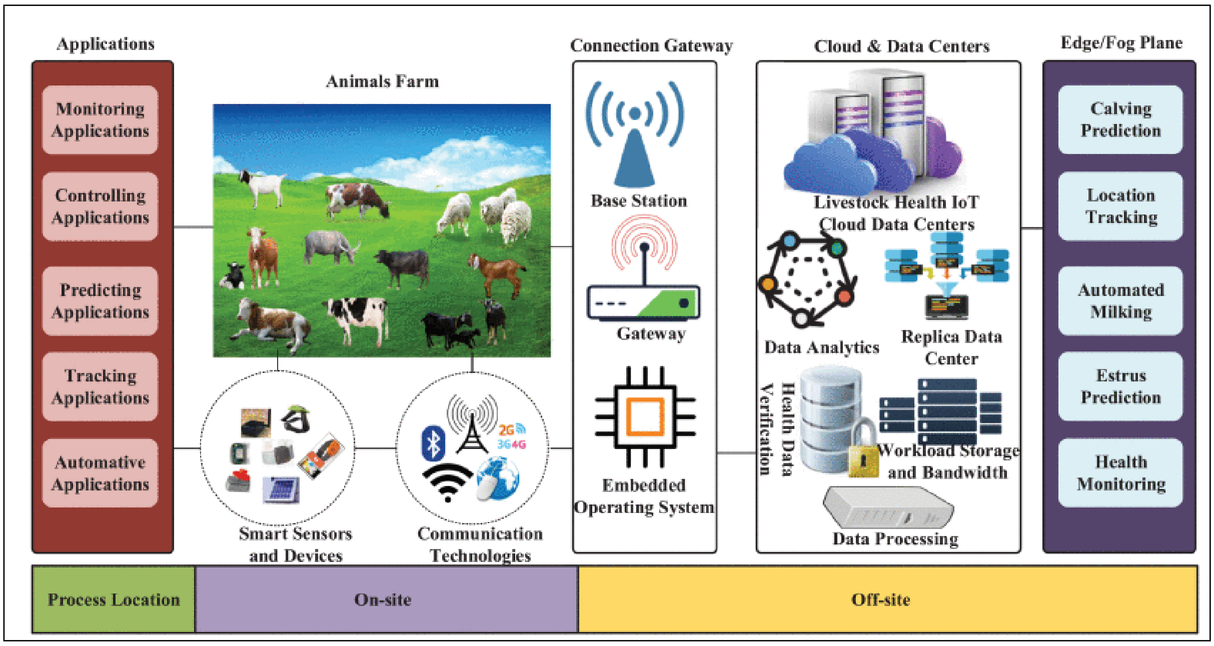


Figure 6: IoT-livestock network infrastructure and technologies
Source: Farooq et al. (2022)

- **Key roles of IoT in livestock management:** monitoring, forecasting, tracking, screening, inspecting, traceability, predicting, automating, documentation and controlling are some of the identified key roles.
- **Smart Sensors and Devices:** IoT-based wearable and non-wearable devices are employed to track animals. To track and find the exact position of animals, multiple tracking devices such as GPRS collars, ZigBee-based tags, GPS collars, Bluetooth tags and Lon Range (LoRa)-based collars have been devised.

- **Communication Technologies:** Communication technologies consist of multiple IoT protocols to transmit livestock data. The most commonly used protocols in this scenario are Internet-related technologies such as Wi-Fi, Long Range Wide Area Network (LoRaWAN), cellular and Zigbee.
- **Connection Gateways:** Most of the sensors and devices are not able to connect to the Internet for data sharing purposes. To overcome this issue, local connection gateways are designed which act as a mediator among all sensors and devices for controllability, security, and connectivity.
- **Cloud and Data Centers:** Cloud would provide scalable and robust storage for a large amount of livestock data. Data analytics and advanced machine learning algorithms can be executed though the cloud.
- **Edge / Fog Plane and Applications:** With the use of application software whether web-based or mobile based of desktop based, the farming communities can monitor and inspect the entire herd of animals in real-time from anywhere across the world without being physically present on the farms. Using the application software, the farming communities can identify and track animals and find the exact position of animals.
- **Future Direction:** There is a consensus that the introduction and integration of G5 network with IoT, cloud computing, big data, blockchain technology and artificial intelligence will provide efficient and flexible solutions for smart livestock farming.

In Indonesia, Imtihan et al. (2021) developed IoT devices for image capturing. The aim of the devices is to replace the role of the Indonesian communities in manually tracing stolen livestock. This is done by tracing footprints and waiting at certain location points, which are considered as the route to be traversed or the final destination of cattle theft. The image files and coordinates captured by the IoT devices are then sent to the District Police.

In India, Joshitha et al. (2021) propose cattle monitoring systems using Long Range Wide Area Network (LoRaWAN). The major components of the system include (i) LoRa based device embedded with GPS module attached around the cow`s neck; (ii) cloud database; (iii) LoRa gateway that communicates with the LoRa based device and cloud database; and (iv) application platform used by the farmers, so that they can monitor the cattle even from remote place. In the same country, Priyanka (2019) proposes a cattle robbery avoiding system and tracking of stolen cattle using IoT, so that herdsmen can monitor the cows and track their movements using the application in the mobile devices. The major difference between the two proposed systems is that the solution presented by Priyanka (2019) is that herdsmen implant IoT sensors in the skin of cattle, instead of using a collar device.

Based on the Italian context, a similar system to Joshitha et al. (2021) was presented by Ojo et al. (2021). Stojkoska et al. (2018) provided a similar conceptual design. The conceptual design has three main building blocks: sensor side (animal collars organized as Wireless Sensor Network), server side (cloud) and client side (represented by the end-users' computers or smartphones). Gbemisola et al. (2018) proposed a similar solution to Stojkoska et al. (2018). The proposed solution has five major components. One of the major components is the Wireless Sensor Network over GSM broadband network. Another important component is the GPS sensor attached to the livestock to locate stray livestock. There is a pulse sensor attached to the livestock for sensing any stray on livestock. The online web service is for recording events. An alarm system is used to alert the farmer about potential threats on the livestock through their smart phones.

The proposed solution by Saravanan & Saraniya (2018) is slightly different from the above proposed solutions. Their solution considers multiple livestock stakeholders rather than just farmers only or herdsmen only. They propose a cloud based livestock management system that uses IoT sensors via wearable collar, smart tags (for uniquely identifying each livestock), smart card (for verifying livestock owner), Quick Response (QR) code reading, mobile device, and web-based interface. The web-based interface would facilitate interaction between veterinary hospital, veterinary doctor, livestock owner/farmer and animal husbandry management institution. The findings of their research showed that the proposed cloud IoT based livestock management system achieved 90% accuracy. This is in terms of sensing the values and predicting the physical gestures like sitting, standing, eating and heartbeat of the animal. Although the system proposed by Saravanan & Saraniya (2018) is a novel concept, the wearable color and smart tag can be easily removed by thieves.

Unlike the above proposed solutions that focused their attention outside of Africa, Abdullahi et al. (2019), Dieng et al. (2017) and Wamuyu (2017) focused on the African context. Abdullahi et al. (2019) proposed a solution based on LoRaWAN technology for addressing issues of cattle rustling in Nigeria. Their proposed solution consists of LoRa sensors attached to the cattle, LoRa gateways to communicate with LoRa sensors and for linking cloud/satellite network, cloud-based software, and an app on mobile device or PC for the farmers to monitor their cattle. Dieng et al. (2017) proposed an IoT solution for preventing cattle rustling in the African context in general. Their system prototype is based on LoRa platform. It is made up of three major components, namely: a LoRa collar that is fitted onto the cow`s neck; a LoRa gateway for receiving signal from the LoRa collar, and then sends the data to the database via the cloud; a database for storing data; a mobile device (smartphone or tablet) for receiving information from the LoRa gateway via the Internet.

Although Wamuyu (2017) focused his research on the African context, his proposed solution is slightly different from Abdullahi et al. (2019) and Dieng et al. (2017). Wamuyu (2017) proposed a conceptual framework for remote identification and tracking of cattle movement in the context of cattle rustling in Kenya. The proposed conceptual framework is based on Wireless Sensor Networks (WSN), rumen sensor module, WSN control unit, Microwave Access (WiMAX) gateway, WiMAX base stations, database, mobile communication, and unmanned aerial vehicles. To evaluate and validate the proposed framework, Wamuyu (2017) conducted a simulation with MATLAB Simulink software; and the results of the simulation showed a few localization errors. Wamuyu (2017) concluded that the proposed framework can be implemented for tracking cattle movement at the village level and extended to harsh terrain when recovering stolen animals.

Maluleke (2018) conducted a qualitative study on the integration of conventional methods and IoT technologies to combat stock theft in Kwazulu-Natal province of South Africa. Maluleke (2018) believes that a single use of these methods cannot effectively combat stock theft. Instead, the author suggested that livestock farmers use different technologies for the proactive and reactive policing of livestock theft in conjunction with the conventional methods. The author suggests an integrated use of the following technologies:

- Three digital tagging systems/electronic identification: (i) injected microchip, (ii) digital ear-tag, and (iii) reticular bolus);
- RFID to monitor the entire national cattle population;
- GPS trackers for localization of livestock;
- Wi-Fi, WSN, ZigBee technologies for livestock monitoring;
- GSM and GPRS technologies for livestock monitoring;
- DNA technology for investigation; and
- Use of drones to track/monitor livestock.

The IoT technologies present a number of implications for the South African context. The implications are explained below.

- **South Africa`s 4IR strategy:** Despite South Africa having a 4IR strategy, no local (community based), district-based, regional, provincial or national IoT programme on how IoT technology could be used in combatting livestock in the country was found in the literature. There is no local (community based) model, district-based model/strategy, regional model/strategy, provincial model/strategy or national model/strategy of IoT in South Africa on how this technology could be utilised in combatting livestock.

- **Country's Readiness to implement IoT:** Soeker et al. (2021) reported that South Africa is in a better position to implement IoT in agriculture due to the country`s current policies, technological infrastructure, access to Internet and mobile technology.
- **Connectivity issues:** IoT devices rely on the Internet to exchange data. However, there are no base stations and Wi-Fi stations in most rural farming areas, which hinders the application of the IoT in agriculture.
- **GSM coverage:** IoT devices can connect to the Internet via a cellular network. South Africa is covered with 4G cellular network, even in some rural areas. The country is moving towards 5G coverage. Use of smartphones with data packages for Internet access is rising. This is an important step towards IoT technology in the country.
- **Cost factor, and the number of IoT devices/sensors and IoT Gateways to be deployed:** IoT infrastructure such as LoRaWAN devices need several gateways to be setup for the farmers to track/monitor their livestock. In communal farming, the livestock farming sector is mostly based on grazing mode. In rural areas, the grazing areas are almost not limited and often very large. The number of IoT devices and IoT gateways is related to cost which is a very important issue in a rural context.
- **Electricity:** Connectivity depends on electricity. Despite the electricity challenge in the country, data from World Bank (2022) indicates that access to electricity (electricity penetration) in the country in 2020 was about 85%.
- **Lack of business cases (use cases):** No business case of IoT technology among communal livestock farmers in South Africa was found in the literature. There is a lack of empirical research on the adoption of IoT by South African livestock farmers.

5.8.5. Deoxyribonucleic Acid (DNA) Technology

In South African, the DNA forensics technology has been adopted by the SAPS and Agricultural Research Council. The Police and Agricultural Research Council use DNA technology for investigative purposes, including cases related to livestock theft (Agricultural Research Council, 2014; SAPS, 2014).

Maluleke (2021) purposively sampled 49 participants to share their experiences on the subject of DNA in combating livestock theft in South Africa. The findings of his study revealed that DNA technology provides irrefutable proof of wrongful convictions, as well as invaluable links to the actual perpetrators of livestock theft. In the same research study, he proposed a DNA conceptual framework in combating livestock theft in South Africa. The major highlight of the conceptual framework is the inclusion of Knowledge Management (KM) and a combination of tracking technologies (RFID, WSN, Wi-Fi and ZigBee) into the already existing general DNA frameworks. In another empirical study, Maluleke (2018) purposively sampled 22 participants to explore the challenges facing the implementation of DNA technology in combating livestock theft in South Africa. The study found that DNA technology was not effectively being used to combat livestock theft in South Africa. The study recommends that the knowledge of DNA technology in combating livestock theft in South Africa should be interpreted, disseminated and implemented correctly by the relevant stakeholders.

Hofmeyr (2018), as an experienced member of SAPS' livestock theft unit for over 20 years, provides insight into combating livestock theft with branding and DNA samples in South Africa. He states that

> "using a forensic approach to stock theft opens a lot of doors. The goal is to gather as much evidence as possible to prevent any doubt about ownership. For this we use DNA technology, the physical matching of ear notches and brands, as well as specific descriptions of animals and photographs of those animals. Even the way a sheep's tail has been docked can serve as a guide."

His insight concurs with Maluleke (2021) that DNA technology provides irrefutable proof of wrongful convictions, as well as invaluable links to the actual perpetrators of livestock theft.

Zwane et al. (2013) provided a review of forensic DNA technology to meet the livestock theft challenges in South Africa. They share the same major highlights with Maluleke (2021) and Hofmeyr (2018). The DNA profiling of exhibits that originate from forensic livestock theft cases can be used to link suspects to either a crime scene or the crime itself. Their conclusion concurs with the two authors that DNA is an irrefutable means of identification of an individual, and can be used to trace the lawful owner of an animal in the presence of a reference sample.

The DNA technology present a number of implications for the South African context. The implications are explained below.

- **DNA forensics process:** The process is long and costly. It can take up six months for the process to be completed.

- **Centralised DNA Forensics Process:** The SAPS do not have their own laboratory catering for this livestock scourge. They rely on one laboratory provided by the South African Agricultural Research Council.
- **Complications:** DNA forensics needs a reference to other livestock in a pool. What if all livestock are stolen? Then it means no reference.
- **Cost Factor:** The farmers have to pay for the DNA tests to be performed.
- **Farmer`s knowledge of DNA Technology:** Farmers have inadequate knowledge and application of the use of DNA technology. DNA forensics requires experts.
- **Constraint:** The biggest constraint to a full large-scale implementation of the technique is the high costs related to the high-tech equipment that is necessary.

5.8.6. Drone Technology

One of the latest ICT developments in precision livestock farming and livestock monitoring is the use of small unmanned aerial vehicles (UAVs), commonly known as drones (Tuğrul, 2023). There are many definitions of drones by various academics, scholars and industry experts. In simple terms, a drone is a remote-controlled aircraft with no human pilot on-board (Sylvester, 2018). With the advancement in ICTs, today`s drones can be equipped with infrared cameras, special sensors, wireless network modules, ultrasonic technology, face recognition, light weight and compact radar, GPS tracker, artificial intelligence, and back-end software tools such as livestock tag readers (Greenwood, 2016). In terms of weight and size, drones are classified into four categories: micro category, a drone less than 1 kg; mini category, a drone between 1kg and 5kg; small category, a drone between 5kg and 10kg; medium, a drone between 10kg and 25kg; and large category, a drone more than 25kg (Tuğrul, 2023).

Drones are in use in various domains such as remote security and surveillance, wildlife monitoring, livestock monitoring and tracking, crop spraying and aerial product delivery and shipping (Aguilera & Gonzalvez, 2017). There are many social, economic, environmental, and technological benefits provided by drones in agriculture. For instance, from a technological perspective, drones can capture very high-resolution livestock imagery under cloud cover and at desired time interval. Drones can provide access to real time information about livestock, and meaningful insights (Greenwood, 2016). Despite the benefits of drones in agriculture, there are concerns from government authorities on the improper use of drones. These concerns include privacy infringements, invasion of reserved airspace and potential aircraft collisions, causing harm to people and animals, personal injury and property damage (Greenwood, 2016).

South Africa is the largest drone market in Africa **(**Drone Industry Insights UG, 2022). New regulations for operating drones in South Africa became effective in 2015 (Drone World, 2018). Despite these developments, the country is underutilising drones in the livestock farming sector. There is a lack of business cases and empirical studies on drone use in the livestock farming sector in South Africa. The only information found on the extensive drone use is pertaining to wildlife population and wildlife monitoring in South Africa. Hodgson et al. (2018), Jiménez López and Mulero-Pazmany (2019) and Save The Rhino (2018) report that, to combat the poaching of endangered rhinos and elephants in South Africa, wildlife rangers are using drones. These drones use satellite imagery, predictive analysis, and hidden cameras over game reserves to monitor wild animals' activity and predict, locate, and track suspected poachers.

In South Africa, drones are regulated by the South African Civil Aviation Authority (SACAA). According to the regulations by SACAA, drone use for data-generation in agriculture should be governed in the same manner as commercial manned aircraft. For this purpose, the regulations require that the operator must: (i) obtain a remote pilot license (RPL); (ii) register the drone; (iii) have an air service license (ASL) from the Department of Transport (DoT); and obtain a remote operator's certificate (ROC) from SACAA (SACAA, 2017; Greenwood, 2016).

Greenwood (2016) and Airborne Drones (2015) shared their insights on the role, benefits and challenges of drones in livestock farming sector. They believe that livestock farmers with a lot of land to cover can use drones to determine the whereabouts of their livestock. In relation to effective surveillance with drones, the technology can be useful for conducting regular surveys of various areas on and around the farms, including fencing, kraals, etc. According to Airborne Drones (2015), the advantage of drone technology is that it can cover large areas, provide a GPS location, as well as visual information, and produce a low-noise footprint, which does not scare animals. They believe that drones can play a significant role in 'pin-pointing' specific locations of livestock thieves, and the technology can lead to the arrest. Despite the benefits, Greenwood (2016) found that the deployment of drone technology has its own challenges, which can be classified under four broad categories: technological, economic, social, and legal and regulatory.

Van Rooyen (2016, 2017) and Du Pisanie (2018) focused on the drone industry in South Africa. Van Rooyen (2016) provided an overview of the emerging uses for drones in livestock farming in South Africa. He highlights that in South Africa there have been several noteworthy recent drone developments. Companies in South Africa are offering drone products, services and solutions. For instance: (i) Drone Clouds provides a subscription service enabling farmers to gain access to very precise, farm-specific data that will assist them with pasture management and pasture sizing, herd counting and herd health (giving early warnings of disease), Moreover, companies such as (iii) ProWings Academy, RPAS Academy and UAV Industries offer drone based training. In addition, (iii) AgDrones, Aerobotics, Drone Solutions, EasyUAV, Haevic and Drone World offer camera drones for farming. In another paper, Van Rooyen (2017) summarises the South African Civil Aviation Authority (SACAA) procedures and guidelines on acquiring and operating a drone in South Africa. The procedures and guidelines include licensing fees, application fees, registration fee, training fees, and costs of purchasing a drone. Du Pisanie (2018) provides a similar summary.

Maluleke (2020) explores the use of drones in policing livestock theft by the selected rural South African livestock farmers. The empirical study revealed three major findings: (i) accessibility remains one of the main challenges for rural farmers; (ii) inadequate related knowledge and application of the use of drones; (iii) lack of capacity and resources (drones); and (iv) common usage of conventional methods such as branding marks, paint marks, ear notching. Soesilo and Rambaldi (2018) carried out an empirical study on drones. Unlike Maluleke who focused on South African context, Soesilo and Rambaldi (2018) took a broader perspective/approach. They surveyed 13000 individuals in Africa to understand the perceptions on the use of drones, and applications. Their results revealed four findings. First, there is general optimism about the prospects of the development of drone technology. Secondly, the majority of participants favoured the use of drones for livestock tracking. Third, the majority of participants agreed that awareness about drone technology is generally low. Fourth and finally, the high cost and complexity of drone technology were perceived as challenges by smallholder farmers.

In France, Vayssade et al. (2019) proposed a drone based solution in combatting livestock theft. They argue that monitoring an entire flock using common solutions such as GPS devices and RFID devices can be expensive. Instead, using drones allows monitoring the flock with only one image and is cost-effective. They then conducted an empirical study on automatic activity tracking of goats using drone camera. The major contribution of their proposal is the development of a method that automatically detects goats from the images and tracks their activity using a combination of thresholding and supervised classification methods. The method was tested on 571 drone images. The results of their methods obtained a sensitivity of 74% for goat detection and 78.3% for activity detection.

Swain et al. (2018) briefly described a business case (use case) of drone technology on a farm in the USA. After 28 head of livestock were stolen from the farm, the farm stakeholders embarked on a pilot project of tracking cattle using drones. The use of drones was supplemented with the use of Google Maps to create electronic borders to identify when cattle are on the property. Drones provided the needed benefits to the farm – drones could be flown over pastures where cattle reside to capture images and monitors cattle. Drones enabled the monitoring of problems caused by feral hogs Drones also detect insects and predator issues with excessive and fast movement. However, Swain et al. (2018) point out the primary limitation with drones is drone battery life. The views of Hoymer (2015) are similar to the business case provided by Swain et al. (2018). Hoymer (2015) indicates that with drone technology, farmers can monitor their animals from the air to ensure that their herds do not become the target of livestock thieves. Similarly, Kobler (2012) briefly described a case where a man in the USA was arrested with drone produced evidence. Kobler (2012) states that "the security officials used a drone to pinpoint the thief`s location on the ranch, and the thief had no clue they used a drone to pinpoint his location".

The drone technology presents a number of implications for the South African context. The implications are explained below.

- **South Africa`s 4IR strategy:** Drones can be integrated with other modern technologies and approaches such as machine learning, IoT, infrared cameras, cloud computing and big data analytics. Despite South Africa having a 4IR strategy, no local (community based), district-based, regional, provincial or national drone programme on how drone technology could be used in combatting livestock in the country was found in the literature. There is no local (community based) model, district-based model, regional model, provincial model or national model/strategy of drone technology in South Africa on how this technology could be utilised in combatting livestock theft.
- **Cost factor and process of acquiring a drone:** The process of acquiring a drone involves licensing fees, application fees, registration fee, training fees, and costs of purchasing a drone. This is a very important issue in a rural context, where livestock farming is predominantly practiced.
- **Drone market in South Africa:** South Africa is the largest drone market in Africa. Agricultural drones are available in the country.
- **Drone skills:** No extensive training is required, because drones are not complicated technologies.

- **Lack of business cases (use cases):** No business case of the use of drone technology among communal livestock farmers in South Africa was found in the literature. There is limited empirical research on the adoption of drone technology by South African livestock farmers.

5.8.7. Big Data and Cloud Computing

There is a relationship between big data, cloud computing and data sources such as IoT (as shown in Figure 7 below). Big data refers to a large set of structured, unstructured or semi-structured data and analysing those data to get the insights of the patterns, trends or themes (IBM, 2022a). Big data also refers to data sets whose size or type is beyond the ability of traditional relational database management systems such as MySQL, Access and PostgreSQL to capture, manage and process the data with low latency. Characteristics of big data include high volume, high velocity, high veracity, high variety and some value (Garner, 2022; IoT sensors, artificial intelligence, mobile devices, online transactions and social media are the main sources of big data. Cloud computing is the location for storage, scale and speed of access (IBM, 2022a). Cloud computing provides an analytic platform for big data. Cloud computing offers services to users on a pay-as-you-go model. Cloud providers offer three primary services: Infrastructure as a Service (IAAS), Platform as a Service (PAAS), and Software as a Service (SAAS).

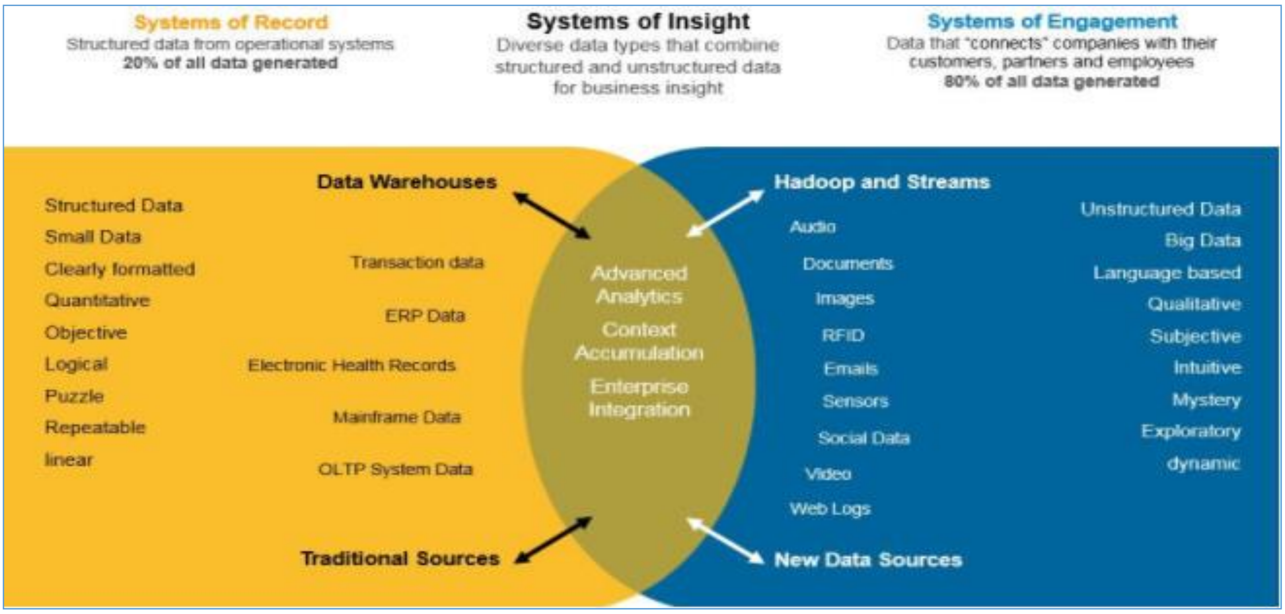


Figure 7: The evolution of big data.
Source: IBM (2022b)

Akhigbe et al. (2021) provide a review of existing literature trends on big data, cloud computing and IoT for livestock management. The contribution of their review is illustrated in Figure 8 below.

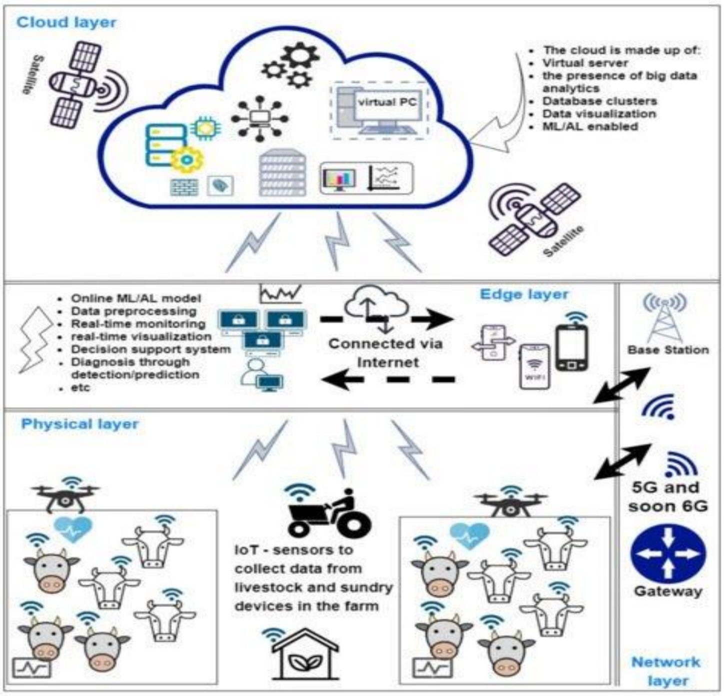


Figure 8: Big Data, Cloud Computing and IoT approach for livestock management.
Source: Akhigbe et al. (2021)

In the context of livestock identification and tracking for mitigating livestock, the physical layer, with the aid of IoT sensors would enable "smart" identification and tracking of livestock. IoT sensors could be deployed along with existing devices such as ear clippers, notches, taggers, barcode, QR code, facial recognition, micro-chipping, radio frequency identification (RFID), ear collar and tags with electronic capacity. Also, IoT sensor could be used along with biometrics (e.g., muzzle prints, iris patterns, and retinal vascular devices). Technologies such as drones, 5G network and GPS network could be used in tracking livestock. The edge layer would enable end-users to identify and track their livestock with their electronic devices such as smartphones, tables, virtual reality devices and augmented reality devices. The cloud layer would enable the storage of livestock data, analytics, machine learning, scale and speed of access of data by end-users. Therefore, these technologies would enable farmers and relevant authorities to manage livestock against theft.

In a blog, Clark (2017) provided his insights on the role of big data in crime prevention. The highlights of his insights are summarised below.

At-risk areas for livestock theft: Big data analytics has the potential to spot patterns and trends, and this information could be used to identify when and where livestock theft is most likely to occur. With enough data, and the means to interpret it, it might even be possible to prevent livestock theft before it happens. With the use of HunchLab, a geographic prediction tool that uses data modelling to predict risk in specific locations, it could be possible to highlight at-risk areas for livestock theft on-screen.

Foreign Countries: In Europe and the USA, police departments are beginning to use big data, machine learning and predictive analytics to understand and prevent crime. This gives them the opportunity to deploy police resources in response to anticipated threats. One example of integrated big data, machine learning and predictive analytics tool is IBM i2 Coplink. This tool allows for the consolidation of disparate data sets (such as arrest records, mugshots, location data and known gang affiliations) into a single dashboard, from which police across different locations can view and share vital information.

Social Media: Social media can facilitate the tracking of stolen livestock. Tools such as Watson Analytics for Social Media can be used to analyse the social sentiment of user-generated content, identifying possible signs of livestock theft and flagging suspicious posts for further review.

Big data and cloud computing present a number of implications for the South African context. The implications are explained below.

- **South Africa`s 4IR strategy**: The country`s 4IR strategy could capitalise on and leverage modern technologies such as cloud computing, big data analytics, and IoT to address livestock theft. Despite the existing 4IR strategy in the country, no local (community based), district-based, regional, provincial or national 4IR programme/strategy/model aimed at combatting livestock in the country was found in the literature.
- **Cloud Computing Infrastructure in South Africa:** According to Illidge (2022), South Africa is in a better position to deploy cloud services for any sector in the country. Major international cloud providers such as Amazon Web Services, Microsoft Azure, Oracle, Huawei and Acronis have begun launching their cloud services in the country. In addition to international cloud providers, the two state owned cloud providers: The Council for Scientific and Industrial Research (CSIR) and State Information Technology Agency (SITA) will be rolling out a big cloud project known as High-Performance Computing and Data Processing Centre (HPCDPC). The HPCDPC will include processing and data

facilities and cloud computing capacity and will consolidate existing public funded data centres (South African Government, 2021).

- **Economies of scale/scope:** Farmers and other related livestock stakeholders could utilise the shared resources; thereby avoid the substantial up-front capital expenditure costs of purchasing their own expensive infrastructure.
- **Lack of business cases (use cases):** There is a lack of empirical research on big data and cloud computing for controlling livestock theft. No business case (use case) on big data, cloud computing and IoT for controlling/mitigating in South Africa was found in the literature.

5.8.8. Machine Learning

According to IBM Cloud Education (2020) and Mohri et al. (2018), machine learning refers to a branch of artificial intelligence and computer science. It focuses on the use of data and algorithms to learn and take decisions related to classification, pattern recognition and prediction. The idea behind machine learning is to imitate the way that humans learn through learning from data, then identifying patterns, making decisions and gradually improving its accuracy. At the core of any machine learning system is a learning method and an algorithm. (Hui Li, 2022) describes three major machine learning methods: supervised, unsupervised, and reinforcement. In a supervised machine learning method, the algorithm makes predictions based on a set of examples that are informed by an input variable that consists of labelled training data and a desired output variable. In an unsupervised learning method, the algorithm is presented with unlabelled data, and it is required to discover the patterns and data groupings without the need for human intervention. In a reinforcement learning method, the algorithm is not trained using sample data in advance. Instead, the learning agent interacts with an environment and learns as it goes by using trial and error based on the feedback it receives from that environment. There are several types of machine learning algorithms such as artificial neural networks, clustering and classification, and regression. From these, a developer can choose when developing a solution for a specific problem. Figure 9 shows an illustration of the relationship between various machine learning algorithms and methods.

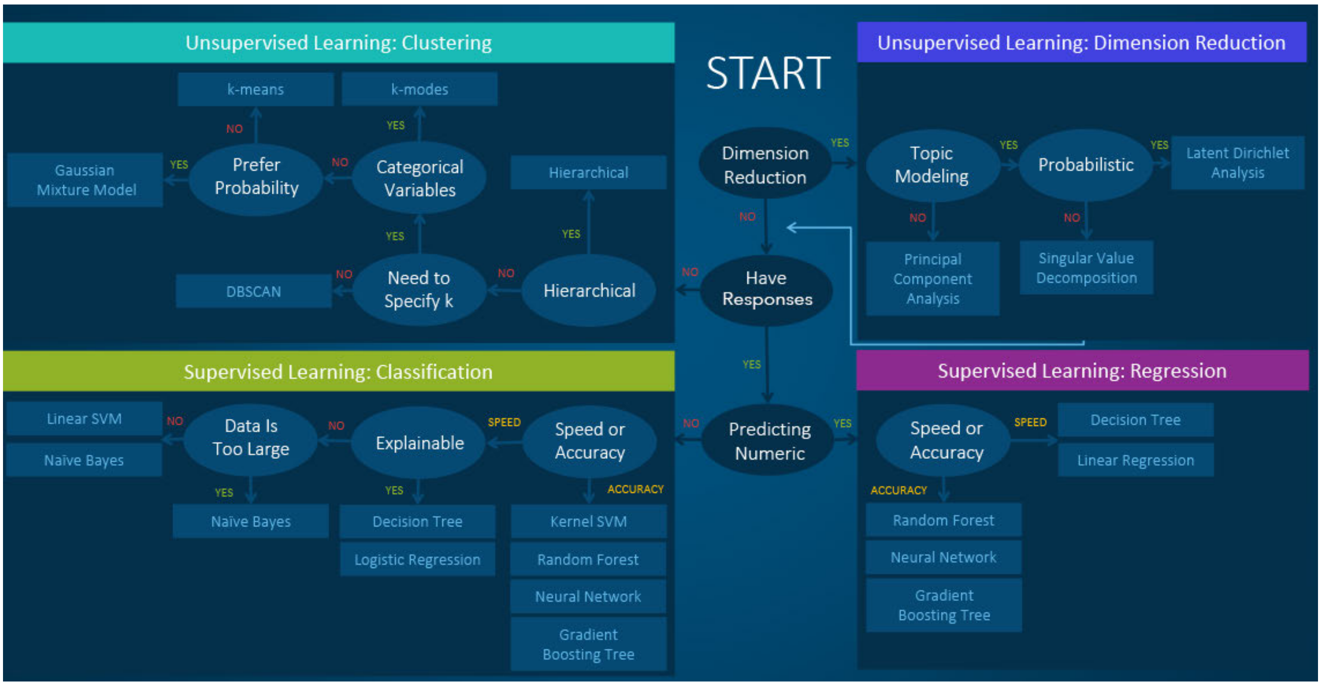


Figure 9: Machine learning algorithms and methods.
Source: Hu Li (2020)

Machine learning methods and algorithms are being applied in various sectors and industries such as government, agriculture, retail, transportation, Information Technology (IT), oil and gas, finance, marketing and manufacturing. They are used to carry out tasks such as, but not limited to, livestock monitoring, harvest yield predictions, pattern recognition, computer vision, robotic control, spam filtering, fraud detection, self-driving cars and speech recognition (Renganathan, 2021).

Garcia et al. (2020) conducted a desktop research on machine learning in precision livestock farming. Sharma et al. (2020) conducted a similar desktop study, but focused on cattle farming; while Kleanthous et al. (2022) focused on sheep. In the context of livestock identification, monitoring and tracking, Garcia et al. (2020 found deep neural networks, Fisher locality, and classification to be most applicable machine learning techniques for precision livestock farming. Garcia et al. (2020), Manhud et al. (2021) and Kleanthous et al. (2022) found that the most widely used Precision Livestock Farming (PLF) data acquisition technologies for machine learning techniques include GPS trackers, RFID tags, drones, IoT collars, and cameras.

In Uganda, Katamba (2019) provided information about a system called "Jaguza Luganda". The system constitutes machine learning technology, mobile application, and battery-powered chip with a sensor that is connected to a radio-frequency identification (RFID) reader. The system uses machine learning algorithm to learn patterns about a cow's movements from the sensor. The battery-powered chip and sensor technology is attached to an animal's ear, and the

RFID reader is able to detect the sensor in the chip from up to 300 metres away. In the event that the farm extends beyond the coverage area, an antenna or radar is installed to bolster the frequency. In 2018, the system was tested on 50 cows in Uganda. Since 2016, about 18,000 battery-powered chips with sensors have been attached to cows' ears. Results showed that the system can track livestock movement and alert farmers through mobile messages, in the event that animals wander beyond farm boundaries. Katamba (2019) concluded that the system has been effective in reducing cases of cattle theft that are rampant in Uganda's livestock rearing regions.

In the same article, Katamba (2019) provides information about drones and machine learning for tracking, counting and monitoring cattle on farms in Uganda. The drones are fitted with high definition cameras and thermal sensing technology. The drones are powered by artificial intelligence and facial recognition to identify individual cows in real-time. The drones are connected to the farmers' mobile phones and computers through a cloud-based system. The algorithm uses two colours as a sign to indicate whether there is a problem with the cow. The red colour indicates that there is something wrong with the cow such as sickness or unavailability, while the green indicates that the cow is fine. Katamba (2019) concluded that there are two major obstacles with drone technology in Uganda: (i) drone regulations were not yet in place in 2019; and (ii) poor Internet connectivity in Uganda is a constraint for scaling out machine learning technology with drone sensors.

Machine learning presents some implications for the South African context. The implications are explained below.

- **Cloud infrastructure:** Machine learning requires large datasets (big data) and cloud-based storage. Official reported cases of livestock theft to the SAPS, unofficial reported cases of livestock theft, stray livestock, livestock kept at animal pounds, and suspicious posts on social media can all form part of large datasets (big data). With the capabilities of cloud computing and machine learning algorithms, the large datasets can be 'auto-analysed' to spot patterns, associations, correlations, and risks.
- **Open Source Machine Learning Platforms:** The availability of open source machine learning platforms such as Tensor Flow algorithms offers low cost. The country can take advantage of open source for cost reduction.

5.8.9. Virtual Fences

Virtual fencing is an electronic method of controlling livestock without physical fencing. Virtual fencing is sometimes called geofencing. Although RFID technology or GSM technology can be used to create a virtual geographic boundary, most virtual fences rely on GPS technology. The virtual fence system comprises of collars or ear tags with a GPS tracker and a battery-powered device that administers the electric shock. Control of livestock involves the containment of livestock within a confined area by using signals from a GPS device that is attached via a neckband or an ear tag of an animal. Using the GPS technology, livestock behaviour and movements are monitored, audio cue signals warns the livestock when they are approaching the virtual fence boundary, and this is followed by an electric pulse (shock) if the livestock do not respond to the audio cue.

Aquilani et al. (2022), in their article on PLF technologies, provided a desktop review of virtual fencing. Virtual fencing is among the technologies aimed at locating animals using GPS technology and preventing livestock theft. Virtual fencing systems such as eShepherd, Agersens, Halter, Vence and Nofence are available on the markets in Europe and the USA. Despite the interesting implications of virtual fencing for controlling livestock, an obstacle to on-farm extensive use of virtual fences is the high cost of the GPS-embedded devices. Providing each livestock unit with a GPS tracker is often economically unaffordable for most farmers, especially small-scale, emerging farmers and rural based communal farmers. The application of electric stimulus on animals in virtual fencing has raised some public animal welfare concerns. These concerns include acute stress, heart rate, body temperate, and behavioural patterns. In response to the public animal welfare concerns, Lee et al. (2021) provide an assessment toolkit that may be applied for welfare assurance of virtual fences when conducting research with farm animals. Another issue with a virtual fence system is GPS device`s battery performance (Aquilani et al., 2022).

In Uruguay, Acosta et al. (2020) proposed a virtual fence system compatible with animal welfare, which avoids electric shocks, based only on sound and tactile stimuli (using a buzzer and a vibrating motor, respectively). The system is made up of various components. It has an electronic device embedded with GPS tracker that is placed on the animal's neck. It has a central server that is able to receive, process and store information. Also, it has a graphical user interface, where the animal's location can be visualized and several parameters can be configured. They performed preliminary tests on cattle, and the results suggest that the stimuli used was aversive to the animals. Marini et al. (2018) developed a similar system, but focused on sheep. After testing their system, they found that the sheep showed a 52% probability of avoiding the electrical stimulus and responding to the audio cue alone.

Sattarov et al. (2019) took a slightly different approach as compared to Acosta et al. (2020) and Marini et al. (2018). They proposed a virtual fence-moving algorithm for circulated grazing. The proposed algorithm handles the movement the animals' group from one fence to another one without using human physical activity. The algorithm creates a new temporal way that covers both fences and allows animals to move between fences safely.

In Italy, Tangorra et al. (2013) developed and tested a virtual fence system to combat cattle rustling. Their virtual fence system was composed of GPS collar devices coupled with the Global System for Mobile Communication **(**GSM), and a software that alerted the farmer when an animal moved outside its grazing area. This is denoted by a virtual perimeter. Their field tests indicate that the system was able to identify when the cattle are mis-positioned and the warning messages were sent promptly to the farmer.

In the South African context and African context at large, there is both a lack of business cases and a lack of empirical studies about the use of virtual fences with GPS technology to combat livestock theft. The cost of GPS modules and GSM modules are the major implications for the South African context. Virtual fences require GPS modules and GSM modules attached to an animal. GPS collar devices are expensive, which is a very important issue in among communal farmers in a rural context.

5.8.10. ICT-based Livestock Recordkeeping Database

In the context of this research study, an ICT-based livestock recordkeeping database refers to a regular collection of structured information or data that is stored electronically in a computer system. An ICT-based livestock recordkeeping database can facilitate accurate, reliable and consistent animal records towards proving compliance with state laws and policies. Simultaneously, with data stored in a record keeping database, the legislation would be fulfilled in terms of controlling animal movements and selling animals. In addition, this would help facilitate quality safe meat by monitoring from farm to table. There are many relational database management systems that can be used for livestock record keeping and reporting (business intelligence) purposes. They include, but not limited to MySQL, Microsoft SQL, Microsoft Access, PostgreSQL, Oracle, and IBM DB2 (Kashyap et al., 2016).

In Malasia, Saad (2016) discusses the preliminary studies for developing an improved livestock database management system using RFID technology and a graphical user interface (GUI). The system aims to enhance the productivity and quality of livestock, specifically cattle, by efficiently managing breeding, feedlot-fattening, dairying, and slaughtering processes. Key functionalities include disease detection through temperature monitoring and selective breeding for better progeny. However, gaps exist in the coverage and integration of these sections within the livestock industry, particularly in Malaysia. The study highlights the need for a comprehensive, cost-effective system for small-scale farmers to improve livestock management and traceability

In South Africa, Odendaal (2020) provided a brief description of record keeping features of a mobile application called “BENGUFARM App”. With the App, farmers can use smartphones or tablets to update livestock (goat and cattle) content into a cloud-based database. The App can operate offline, and then allow the farmers to update content once Internet access is restored. Data can be imported into the cloud database via external applications such as Excel. It is also possible to record livestock data on an electronic ID (EID) reader if a farmer uses radio frequency identification tags. Most Bluetooth-enabled EID readers can be linked to the App.

Molotsi and Makombe (2019) designed a web-application recordkeeping database for smallholder sheep famers in the Western Cape Province of South Africa. The database design has functions such as editing, deleting and adding information whenever a farmer needs to. The databased designed by Molotsi and Makombe (2019) has some limitations: (i) issues with unique identification of sheep: the identification numbers for sheep are only unique at farm level, which means they are not unique in South Africa. This does not give the farmer assurance of proof of ownership of sheep when they are stolen; (ii) Lack of accuracy**:** no unique farmer information, e.g. South African ID or passport number that links the farmer to the sheep or farm to prove ownership of sheep or farm.; and (iii) Manual Data Entry: too much manual entry of data (e.g. manual entry of tag numbers) into the database, which could be automated.

Çelikyürek et al. (2019) conducted a desktop research study on database usage and its importance in livestock. Not only a livestock recordkeeping database would enable safe guarding against theft and compliance with laws, but it can be beneficial to the farmer on farm-level: (i) the farmer can quickly access the data stored in a recordkeeping database; (ii) the farmer can filter data according to all kinds of criteria and the desired data can be reached quickly; (iii) the long term decisions, or medium-term or short-term decisions can be implemented quickly with reports generated from data stored in a livestock recordkeeping database. Databases can benefit livestock farmers in many cases such as herd management of animals, trade of livestock, and counting of livestock.

The ICT-based livestock recordkeeping database (flock management) presents two implications for the South African context. The implications are explained below.

- **Livestock Registers:** In South Africa, the Stock Theft Act and the Movement of Animals and Animal Produce Bill emphasise the importance of livestock documentation, registers and record keeping.
- **No centralised database:** In South Africa, there is no official centralised district-based database, regional database, provincial database, or national database for livestock population records/registers and reporting. Livestock numbers/statistics in the country are based on estimates and community surveys.

5.8.11. Global System for Mobile Communications (GSM) Technology

Global System for Mobile Communication (GSM) networks can be used for livestock location tracking (Ojo et al., 2022). It is a digital cellular technology used for transmitting mobile voice and data services such as SMS, MMS, USSD, Email and phone calls. The technology is the most widely accepted standard in telecommunications and it is implemented globally (GSMA, 2021). Figure 10 shows a general composition of GSM network.

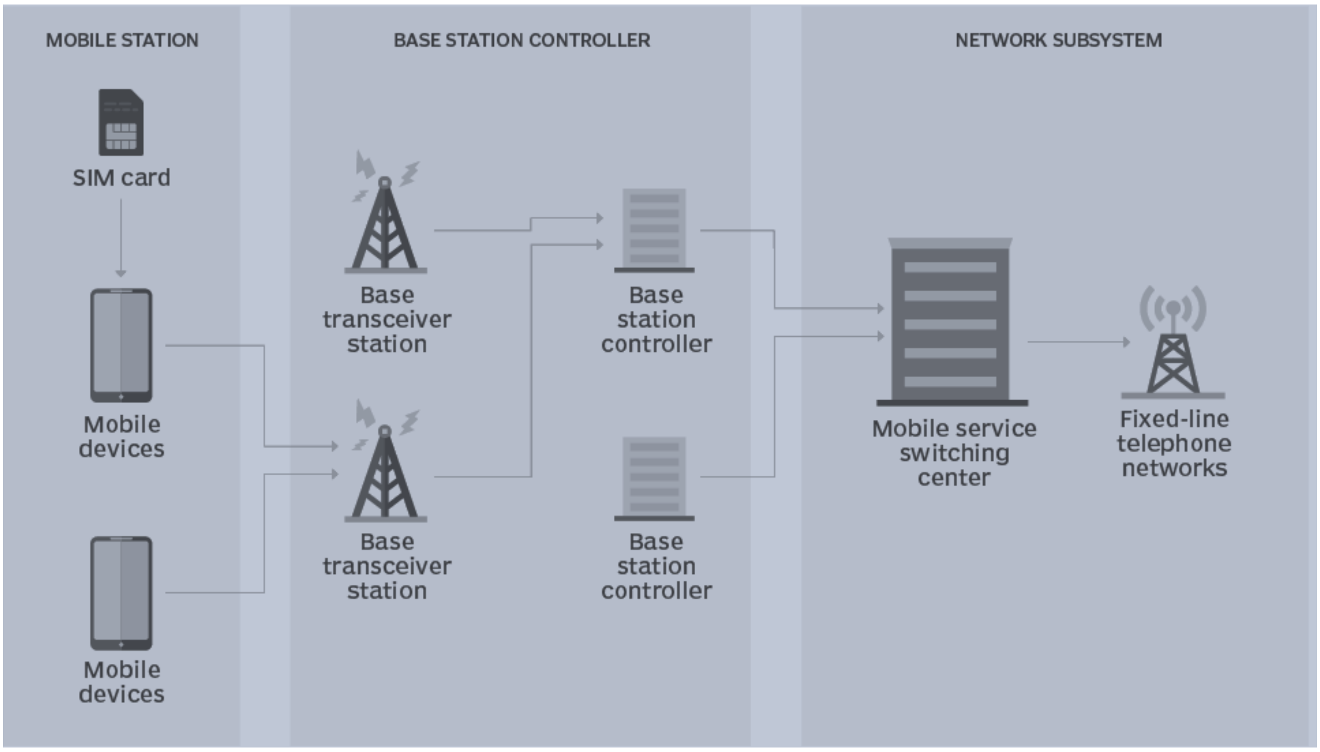


Figure 10: Elements of GSM network.
Source: Ndungu & Mixon (2018)

Over years and throughout the world, the GSM technology has evolved from standard mobile phone services to high-speed data capabilities. For example, GPRS (General Packet Radio Service) is a widely deployed wireless data service (e-mail on the move, multimedia messages, social networking and location-based services), available now with most GSM networks. In the early 2000s, GSM networks were upgraded with Enhanced Data rates for GSM Evolution (EDGE) technology, which can provide up to three times the data capacity of GPRS. We are now in the era of 4th Generation (4G) and moving towards the era of 5th Generation (5G) cellular networks (GSMA, 2021). The evolution of GMS technology is illustrated in figure 11 below.

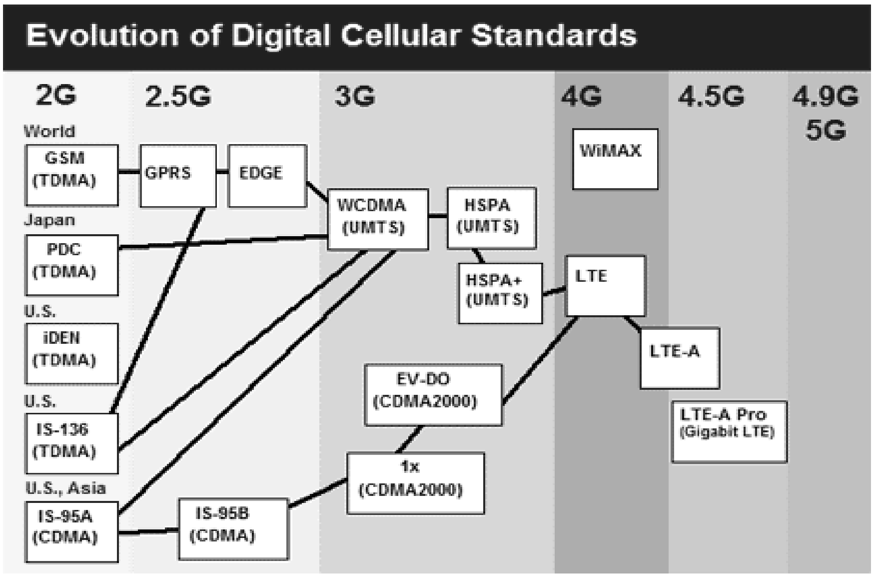


Figure 11: The evolution of GSM technology.
Source: GSMA, 2021; PCMag, 2023

Sirotek & Hart (2019), Stojkoska et al. (2018) and Raizman et al. (2013) demonstrate the empirical evidence of GSM technology for livestock location tracking. Sirotek & Hart (2019) tested GSM technology for livestock location tracking in Czech Republic. Their field tests were conducted in different environments. These include forests, trucks, countryside, open landscape, city, and farm buildings. Raizman et al. (2013) highlights the feasibility of tracking cattle using GSM collars. In comparison to GNSS, GSM cellular communication has some major drawbacks. For instance, radio coverage of cellular communication such as 3G, 4G and 5G is not guaranteed everywhere, especially in the mountainous areas, and areas commonly affected by adverse weather conditions (Ojo et al., 2022).

In South Africa, Kriel (2020) provides a brief description of a real-time monitoring mobile application called “Farm Ranger App”. The App operates in conjunction with the GPS collar devices and Google Maps to assist farmers with livestock monitoring and tracking, and help prevent livestock theft. A GPS collar device on the animal’s neck transmits a signal to a farmers’ cell phone when the animal moves suddenly and unexpectedly. The main constraint among livestock farmers especially emerging farmers, smallholders and communal framers would be the affordability of the App. For instance, the price of “Package B” of the App is about R6000 per GPS collar device, and in addition, there is a monthly subscription of R185. Maluleke (2017) provided a similar description of a similar mobile application called “Agri-Alert”.

To demonstrate the tracking stolen livestock or stray livestock in Czech Republic, Sirotek & Hart (2019) explored the possibilities of monitoring cattle via GSM technology and GPS technology. In their research, they tested both technologies in different well-defined environments, and then compared the two technologies for accuracy, reliability, speed and consistency. Their results showed that localization by GSM appeared to be highly inconsistent and less accurate. They recommended a combination of both technologies for tracking stolen livestock or stray livestock because GSM is more reliable, while GPS is more accurate. They reported two issues with their system: (i) both technologies do not have enough precision to monitor cattle behaviour; and (ii) battery consumption issue – both technologies consume a lot of power.

To address conflicts that arise due to animal rustling and animal identification problems among the pastoral community in Ethiopia, Lemma et al. (2019a) proposed a system based on GSM-GPS enabled devices, GSM/WCDMA wireless network and algorithms running in edge clouds. They evaluated (experimented) the system using a simulated data and they found that the system worked well to solve the problems of animal rustling and animal identification problems. However, they discovered that their system had some limitations: (i) the system did not apply the concept of virtual fence to restrict animals’ movements in a certain place, and (ii) the system did not use machine learning approaches, which can help detect abnormal activities based on the animal behaviour.

In Uganda, Katamba & Mutebi (2017) provided details about the mobile application called “Jaguza Livestock App”. The App monitors cattle movement/whereabouts, which enables the prevention of livestock theft. The App works with RFID tags that have unique animal identification, solar-powered gateways that send data from RFID tags to a centralised web server, a centralised server that stores livestock data, and end users devices (personal computers and mobile phones). To cater for end users with basic/feature mobile phones, the App uses SMS, USSD and IVR. As of 2017, the App was operational in over 20 communities in 62 local farms in Uganda.

The GSM technology presents some implications for the South African context. The implications are explained below.

- **GSM network penetration/coverage in the rural areas:** Data from a survey on mobile network experience report conducted by OpenSignal shows that South Africa is covered by GSM modern networks – 3G, 4G technologies (OpenSignal, 2022).
- **Mobile phone use and adoption in the rural areas:** Mobile phones are the most adopted ICTs by rural populations.
- **Lack of business cases (use cases):** Despite the widespread adoption of mobile phones in South Africa, no business cases (use cases) of mobile technology adoption among communal livestock farmers to combat livestock theft in the country was found in the literature.

5.8.12. Bluetooth Technology

According to Bluetooth SIG (2021), Bluetooth is a short-range wireless technology. It is used for exchanging data (text, video, audio and graphics) between nearby fixed and mobile devices over short distances of up to a maximum of 10 meters. Although Bluetooth technology was initially developed purely for the exchange data between devices, Bluetooth Low Energy (LE) is now also widely used for localization purposes. This has been driven by the need for device positioning technology to address the increasing demand for high accuracy indoor location services. In addition, Bluetooth technology can be used for audio streaming, and device networks (e.g. point-point, broadcast and hybrid). Due to the rising demand of mobile devices and developments in IoT, it is estimated that about seven billion Bluetooth enabled devices will be shipped annually to the developing countries by 2026 (Bluetooth SIG, 2022)

In Kenya, Makario & Maina (2021) proposed a Bluetooth Low Energy (BLE) based system for livestock identification, tracking, counting and localization in the farm. Their system consists of peripheral (collar) devices that advertise animal data and mobile client (central) devices that wirelessly scans for collar devices in an area of radius 8m - 16m for data. Collar and central devices form a Low power Wide Area Network (LPWAN) made of a large Bluetooth piconet (an ad hoc network connecting all collar devices and central device) network. Their system architecture is illustrated in figure 12 below. Their system has some constraints: (i) Bluetooth technology covers a very short range in terms of geographic area; (iii) the system is operational on farm level within short range - outdoor grazing where livestock can move beyond the determined area or when thieves steal livestock away from the farm remains an issue.

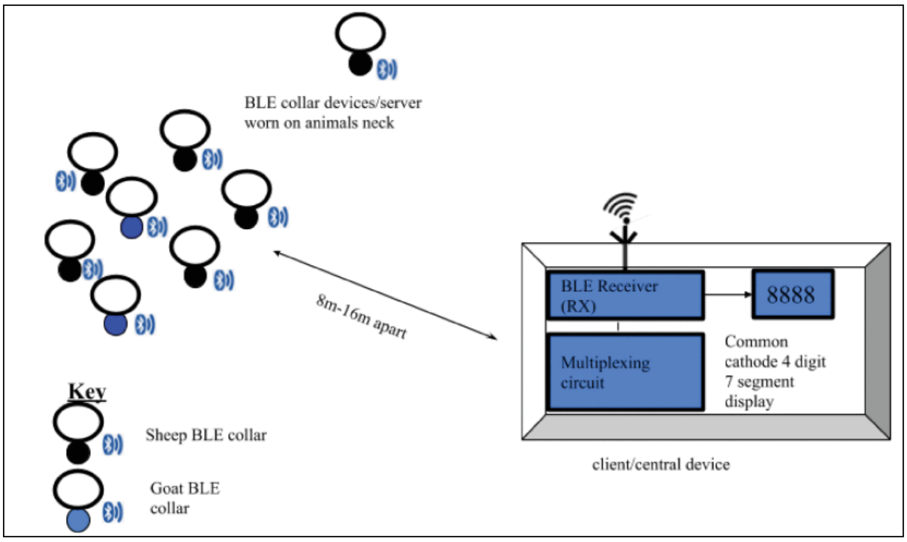


Figure 12: Architecture of a Bluetooth Low Energy (BLE) based system for livestock identification, tracking, counting and localization in the farm.
Source: Makario & Maina (2021)

In Spain, Maroto-Molina et al. (2019) took a comprehensive approach to include GPS technology, cloud computing, and mobile phone technology. They developed a Bluetooth-based and IoT-based system to monitor the location of a whole herd. The system architecture is illustrated in figure 13 below. The system requires some animals of the herd to be fitted with GPS collars connected to a Sigfox network and the rest with low-cost Bluetooth tags. They tested their system on 50 cattle and 50 sheep in a commercial farm. The results demonstrated that a low collar/tag ratio enable the effective monitoring of a whole sheep herd.

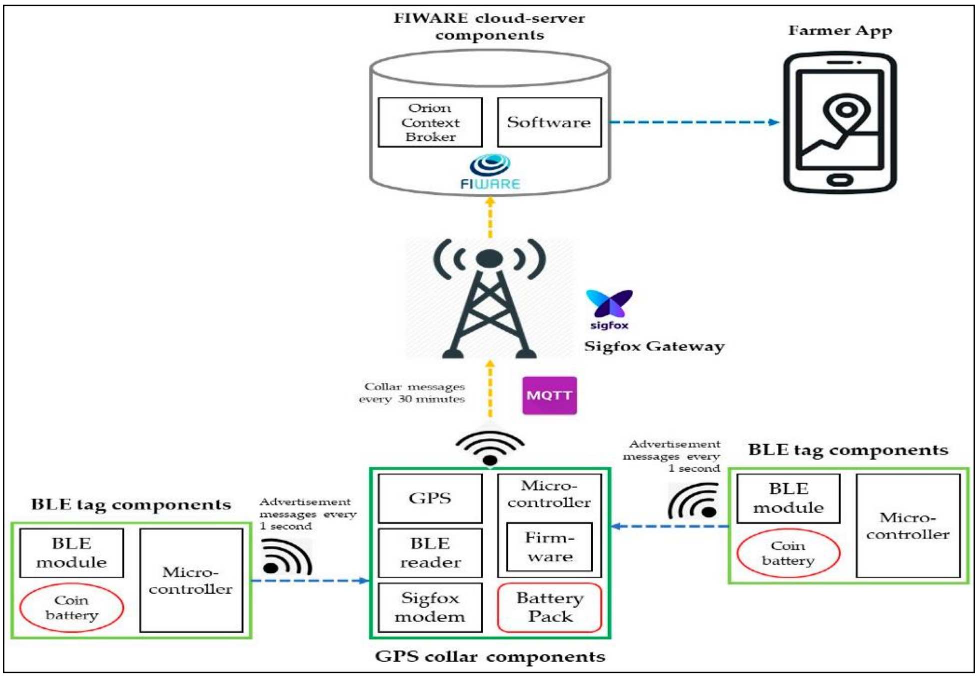


Figure 13: Architecture of a Bluetooth-based and IoT-based low-cost system to monitor the location of a whole herd.
Source: Maroto-Molina et al. (2019)

The Bluetooth technology presents some implications for the South African context. The implications are explained below.

- **Low cost:** Bluetooth is a low-cost technology. Cost is an important factor for communal livestock farmers.
- **Easy and fast implementation:** Most mobile devices are already embedded with Bluetooth technology. The technology is easy to setup, configure and use.
- **Cost implications:** GPS collars are expensive. Affordability would be a constraint to/for communal farmers and emerging farmers.
- **Short Geographic coverage:** Stray livestock, cross-border theft, shared grazing areas in the communal livestock sector.
- **Durability/Sustainability Implication for Tags/Collars:** Bluetooth tags/collars are not permanent identification and tracking methods; they can be removed by thieves.

5.8.13. Immersive Technologies (Virtual Reality, Augmented Reality, Mixed Reality)

Various researchers, authors, academics, and industry experts define immersive technology from different perspectives. In the context of this research study, immersive technology refers to a technology that enables users to interact with simulated environments and objects, blurring the line between the real world and the digital world (Lee et al., 2013). Figure 14 below illustrates a typical immersive analytic cycle application in livestock farming. Immersive technology covers a range of technologies such as Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR), Three Dimensional (3D) games and simulations. This section focuses only on VR, AR and MR due their applicability in livestock identification, tracking and monitoring.

Figure 14: A typical immersive analytic cycle application in livestock farming.
Source: Klaas & Roopaei (2021)

To explore the potential of Augmented Reality (AR) in precision livestock farming in Australia, Zhao et al. (2017) propose a method that utilises AR to assist livestock farmers to identify and locate a specific cow within large herds. Their method consists of two major elements: (i) GPS collar devices attached to cows; and (ii) digital camera and on-board GPS on a mobile device to identify and locate a selected cow and show it on our mobile application. The method is based on the idea of integrating GPS data with computer vision (CV), machine learning, and mobile AR application. In terms of functionality, the method would allow the farmer to search for a cow by its unique identification, and then display information associated with a selected cow visible on a screen. The main limitation of the method is that no fieldwork experiments/tests were conducted; therefore, it is difficult to establish the performance and accuracy of the method.

In India, Simon & Prasad (2017) developed a system called “virtual herding system”. The purpose of their system was to examine the potential combining the Augmented Reality (AR) with Virtual Fencing (VF) to control and herd the animals with a proactive approach. They tested the system on one cow in a farm. The findings revealed that the cow responded to stimulus when approaching the boundary.

In Italy, Caria et al. (2020) and Caira et al. (2019) focused their research on smart glasses for Augmented Reality (AR) in precision livestock farming. Caria et al. (2020) selected 16 participants to examine the performance and usability of GlassUp F4 smart glasses for AR on a group of cows. The 16 participants performed the identification and grouping of cows, reading different types of contents on the augmented reality device optical display. Results showed the overall satisfaction on the usability of the SG was positive, allowing farmers to properly complete the animal identification and selection process. The implications discovered from the results showed that the type of augmented visual stimuli presented to the farmers represents an important aspect that needs to be carefully analysed in future studies. In another study carried out by Caira et al. (2019), some laboratory and farm tests were performed to evaluate the implementation of GlassUp F4 smartglasses.

Immersive technologies present some implications for the South African context. The implications are explained below.

- **Market for Agricultural Immersive Technologies:** According to Caria (2020), there are no AR or VR commercial solutions/products specifically available for the agricultural field, despite the potential of this technology to help farmers
- **Costs of AR or VR commercial gadgets:** Specialised AR gadgets and VR gadgets are expensive. For instance, the price of Meta Quest Pro VR headset was about $1,499.99 (i.e. about R27,168 in South African Rands) (PCMag, 2022), while the price of Google AR Glasses was about $999 (i.e. about R18,106 in South African Rands) in 2018 (Tiffany, 2018). Cost is a very important factor in a rural context and among communal farmers.

5.8.14. Social Media

In Europe and North America, the police forces harness social media and instant messaging in crime prevention. Nunns et al. (2022) in their empirical research study on farm crime prevention methods used by the police force in rural England and Wales found the use of community updates and crime updates via: (i) WhatsApp groups; (ii) Farm Watch text message groups; (iii) alert messaging systems; (iv) Twitter; (v) email alerts; and (vi) seasonal magazines and weekly newsletters. These technologies also facilitate liaison with key stakeholders and partners such as rural crime advisory groups, the National Farmers Union, and cross-border operators. Cognac (2018) provides a summary on how the police force use social media in crime prevention in USA. The Hawthorne California Police Department has a social media program and crime reduction strategy in place, wherein they use mainly Facebook and Twitter to engage with communities. The use of social media has helped the Hawthorne California Police Department to identify suspects within minutes of an image being posted on social media.

In South Africa, Clack (2015) conducted a case study on the role of social media in livestock theft. He used case studies from the Facebook group called "Veediefstal Aanmelding en

Statistieke (VAS) [Livestock Theft Reporting and Statistics]" to illustrate how social media was used to identify possible livestock theft suspects and the interrelationships between the various role-players. The Facebook group VAS attracted more than 500 members within the first 24 hours of its creation. In the same year of VAS's creation, members of VAS started posting information about stolen/missing livestock on VAS. Clack (2015) highlights an example of one instance of posted information on VAS, which led to the arrest of the suspect of livestock theft. In conclusion, Clack (2015) believes that social media networks can contribute to the apprehension of the offenders (livestock thieves) as well as involving other related information that could lead to reduction in livestock theft. Clack recommends the involvement of the various role-players (criminal justice system, communities and farmers) via different social networks in preventing livestock theft. He believes that social media should be utilised more widely to prevent crimes as a whole and to apprehend suspects.

Bunei (2017) shares similar suggestions with Clack (2015). Bunei (2017) suggests that African countries need to strategically invest in technology to fight stock theft, and enable all role players (law enforcement agencies, communities, farmers, slaughterhouses, etc.) to contribute intelligence data. Bunei (2017) points out that social media platforms such as Facebook, WhatsApp and Twitter can be effective methods for communicating with citizens and reporting of livestock thefts. It is important that farmers be empowered and encouraged to register with social media technologies. He mentioned one example of a chief in Kenya, who used twitter to share information about stolen livestock.

Social Media present a number of implications for the South African context. The implications are explained below.

- **Social media adoption**: There is a high rate of social media adoption in South Africa. It is estimated that there were about 22 million social media users in South Africa in 2020 (Kepios, 2022). The country could take advantage of this adoption to use social media platforms as sources of big data and analytics.
- **Social media strategy:** Despite South Africa having a high rate of social media adoption, no provincial or national social media strategy/model related to controlling/mitigating livestock theft crimes in South Africa was found in the literature.
- **Viral posts**: Viral content includes any form of online content (image, video, text, audio, etc.) that spreads at an extraordinary rate and receives massive reach and high engagement. Social media has the 'power' to facilitate viral content. Since the country has a high rate

of social media adoption, viral content related to livestock crimes could be filtered and analysed.

- **Integration with other systems**: Social media platforms can be integrated with technologies such chabots, IVR and USSD to enable instant community linkages and information exchanges among livestock stakeholders.

5.8.15. Remote-Activated Camera Trapping and IP Camera Surveillance of Livestock

A remote camera trap and an Internet Protocol (IP) camera are two related technologies. The fundamental function of both technologies is based on capturing and recording video/image/audio data. A remote camera trap does not have to be connected to a network or Internet. Rather, it can be setup to record data locally on a memory card within the camera. Coll (2022) defines IP camera as a robust camera connected wirelessly or in a wired manner through a network and usually the Internet. The use of remote-activated camera traps and Internet Protocol (IP) cameras is another approach to monitor, inspect, identify, count, estimate, track and locate livestock. The key capabilities embedded into these two related technologies are motion sensitivity (also known as visual sensing), and video/image/audio capture. These two key capabilities enable remote-activated camera traps and Internet Protocol (IP) to record the presence of a species at a location, and record their movement in an efficient manner.

Kays et al. (2020) demonstrated the empirical evidence of remote-activated camera traps as a relevant technology for livestock tracking; when they studied animal movement and distribution. However, the weaknesses/limitations of their field tests and analysis was that the camera traps were not networked and the data retrieval was non-real-time (i.e. by manual retrieval of memory cards). The study conducted by Yue et al. (2013) on automated identification of animal species in camera trap images is an improvement of Kays et al. (2020), because of machine algorithm. In the context of agriculture, environment and rural affairs, Coll (2022) mentions that IP Cameras have been installed and adopted in three locations in CAFRE in the United Kingdom (UK). Most of the empirical studies on camera traps focused on wildlife research and conservation (Glover-Kapfer et a., 2019; Trolliet et al., 2014; Yue et al., 2013).

5.8.16. Low Power Wide Area Network Technologies

Wireless personal area networks (e.g. RFID, Bluetooth and Z-wave) and wireless local area networks (e.g. Wi-Fi and Zigbee) suffer from technical constraints such as short distance coverage. These technical constraints have led to the evolution of a new paradigm of Internet of Things (IoT) known as Low Power Wide Area Network (LPWAN), as illustrated in figure 15.

below. According to Chaudhari & Borkar (2020) and Crowcroft et al. (2018), LPWAN is a wireless technological solution for long range and low power Internet of Things (IoT) and machine-to-machine (M2M) communication applications. Some of the key application characteristics of LPWAN include low bandwidth, low transmission data rates with small packet data sizes, low device and deployment costs, and long battery life operation (Crowcroft et al., 2018). The major technologies 'fuelling' LPWAN include Sigfox, LoRaWAN, Narrowband IoT (NB-IoT), and long term evolution (LTE)-M (Bharat et al., 2020; Chaudhari & Borkar, 2020; Crowcroft et al., 2018). Each of these technologies has benefits and limitations.

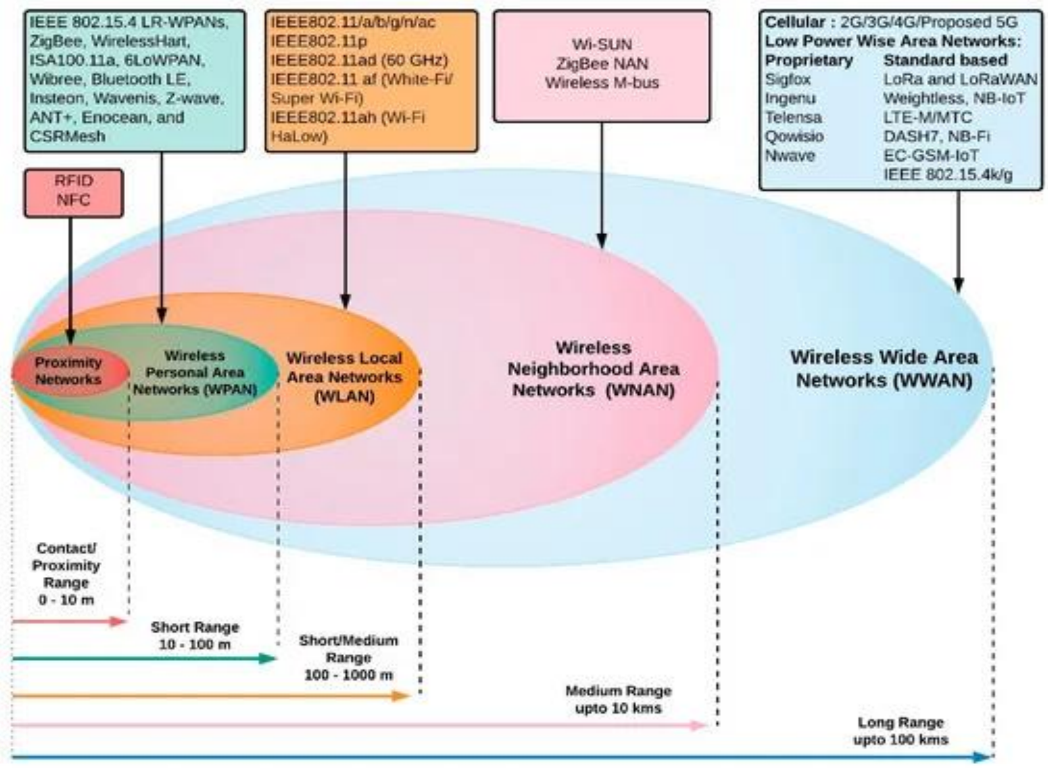


Figure 15: LPWAN technologies and associated technologies
Source: Chaudhari & Borkar (2020)

In terms of architecture, the prominent topologies of LPWAN are star and mesh (Chaudhari & Borkar, 2020). At the core of LPWAN architecture are node/sensor devices, gateway devices, wireless access and connectivity to the Internet and the cloud. In a LPWAN, nodes can connect to each other; but to connect to the Internet and the cloud, the node/sensor devices connect through gateways. In the context of livestock tracking, the basic function of a node/sensor device would be to collect data about livestock such as location identification and behavioural patterns. The basic function of the gateway is to forward the collected data by the node/sensor devices to the computer servers via the Internet and the cloud.

The empirical evidence of LPWAN for livestock location tracking was demonstrated by Reis et al. (2021), Casas et al., (2021), Ilyas & Ahmad (2020), de-Oliveira et al. (2019), Maroto-Molina et al. (2019), Germani et al. (2019), Ikhsan et al., (2018), Zinas et al. (2017), Dieng et al. (2017), Zinas et al. (2017). For instance, Reis et al. (2021) demonstrated livestock location tracking and activity of pastured livestock using the wearable sensor attached to an animal in the form of collar, the gateway, and cloud-based server. Ikhsan et al. (2018) simulated a smart livestock monitoring system using a sensor collar hung on the cow’s necks, and mobile gateway.

Various LPWAN-based sensor devices have made their way into marketplace. For instance, Chipsafer's wireless sensor is an electronic device developed by Uruguayan Start-up Company that can be attached to a cow either as an ear tag or as a collar to help farmers control cattle rustling and diseases, and track cattle movements (Semtech, 2019; Swedberg, 2018). The device is embedded with battery, solar panel, and Long Range Wide Area Network (LoRaWAN) transceiver chip. The device has a built-in GPS node, and water-proof casing. The device employs long-range wide-area network (LoRaWAN) technology to transmit signals wirelessly (ChipSafer, 2017; Swedberg, 2018).

One of the major advantages of Chipsafer's wireless sensor is that it operates at a longer range than RFID devices. It can communicate with a LoRaWAN gateway at a distance of up to 13 kilometres. Another advantage of Chipsafer's wireless sensor is that it does not need Wi-Fi or cellular technology to transmit signals. Instead, the device needs a LoRaWAN gateway to transmit signals about an animal`s movement and behaviour (Swedberg, 2018). The major disadvantage of the device would be the cost of purchasing Chipsafer's wireless sensor, especially for communal farmers, small-scale farmers and emerging farmers. For instance, one Chipsafer's device for one cow would cost a farmer between $10 (about R130) and $50 (about R670) (Semtech, 2019). Another major disadvantage of the Chipsafer's wireless sensor is the cost and installation of several LoRaWAN gateways in the cattle ranch areas. The installation of LoRaWAN gateways would be a very costly exercise in South Africa since many livestock farmers, especially communal farmers are located in vast cattle ranch areas. The Chipsafer's device can be easily removed by thieves, since the devices can be attached to the cow as an ear tag or collar or collar tag.

5.9. Commercial Livestock Management Systems

There are a number of commercial livestock management software packages available on the market. The commercial software packages range from desktop applications to website-based applications, mobile applications, and SMS based applications. The software packages include CattleWatch, Find Me, Go360bioTrack, Cowsense, CattleMaxCS, CelMax, Farm Ranger, and BhenguFarm. The key features and functionalities of these software packages are briefly described below. The last part of this section describes the shortcomings of these software packages.

CattleWatch is a web-based and mobile app software that enables remote monitoring of livestock (cattle, sheep and goats). The key features and functionalities of CattleWatch software include: (i) the ability to integrate with satellite/GPS collars for tracking the location of livestock; (ii) automatic counting of livestock (iii) livestock theft early warning alerts; and (iv) geo fencing (Cattle Watch, 2017). The FindMe software has similar features and functionalities as CattleWatch software. The FindMe software enables farmers to receive theft early warning alerts via SMS on their phones (Nel, 2015). Farmers can use smartphones to view animal details. CattleMaxCS has same the features and functionalities as Go360bioTrack. Other similar/related commercial systems include CelMax, Farm Ranger, and BhenguFarm (der Merwe, 2019; Uys, 2017).

The commercial software packages described above has many drawbacks. The first major drawback is that all the software packages are intended for use at the farm level, by commercial farmers in particular. None of the software packages cater for use by other livestock stakeholders such as SAPS STUs, and Stock Theft Preventative Forums. Livestock theft in South Africa is a national problem that cannot only be addressed at farm level, but at a multi-stakeholder level. The second major drawback among the described commercial software packages is the lack of capacity to handle large volume of data; South Africa has a population of over 20 million cattle, sheep and goats combined. The third drawback is that the commercial software packages described above lack integration with current traditional livestock identification methods such as branding marks. They lack integration with tamper-proof traditional livestock identification methods such as biometrics and DNA forensics. The fourth disadvantage is that is that the commercial software lacks integration with business intelligence applications. The last and most important limitation/drawback relates to costs. The CattleWatch and FindMe software packages rely on GPS collar for tracking livestock; GPS collars are expensive, especially for communal farmers. GPS collars need constant power supply from the batteries or solar source. Also, GPS collars can be easily removed by thieves.

5.10. Addressing the Research Questions

The findings in relation to the research questions obtained in this chapter provide valuable insights into the information system components and features necessary for inclusion in the sought-after model for controlling livestock theft in country. Table 16 below provides a summary on how this chapter has addressed some of study`s research questions.

Table 16: Addressing the research questions – chapter 5

Research question	Key Findings in relation to theory variables
Research Question 2: Who are the important actors involved 'in the fight against' livestock theft in South Africa?	Various actors with different interests, links and relations as revealed have been found – e.g. Agricultural Research Council, National Council of Societies for the Prevention of Cruelty to Animals, SAPS, farmers.
Research Question 3: How can the important actors be organized to control livestock theft in South Africa?	Some form of collaborative approach by various actors has been identified in the literature – e.g. SAPS and Agricultural Research Council for DNA forensics.
Research Question 4: What is the nature of use of livestock identification methods and tracking methods by the human actors for controlling, mitigating, or combating livestock theft in South Africa?	DNA based system, and social media.
Research Question 5: Which ICTs have been adopted by the human actors involved 'in the fight against' livestock theft in South Africa?	Social media.
Research Question 7: What are the insights, attitudes and perceptions of research participants towards the use of ICTs for controlling livestock theft in South Africa?	Drones are expensive. GPS trackers are expensive. IoT is complex to implement and deploy. DNA is expensive and a long process. Commercial livestock management systems and apps are expensive. Most of electronic livestock identification methods and conventional livestock identification methods do not offer a permanent solution.
Research Question 8: What are the information system components required to develop a holistic and national livestock identification and tracking system for controlling livestock theft in South Africa?	Various information system components in the form of actors, actants, translation, and networks have been found in the literature.

Source: Author`s own illustration based on literature review and study`s research questions

5.11. Identified Gaps in the Literature

Outside of South Africa, there are many scholarly papers from the perspective of ICTs and livestock theft. However, the explanation of complex socio-technical processes of actors by 'mapping' their actions, relations and interactions is lacking in the literature; because majority of the encountered research papers did not adopt ANT or similar theory as the theoretical lenses. The majority of the proposed ICT-based solutions/systems towards livestock theft are mainly targeted at farm level, with farmers being the main users of the systems. In South Africa, livestock theft is an organised crime and a cross-border crime that cannot be solved at farm level only, but rather through diverse stakeholders. The majority of the proposed solutions/systems towards livestock theft did not consider animal welfare factors, livestock identification standards, country's cultural issues, institutional factors, formal/inform structures, government agencies, and socio-economic conditions of the livestock farmers.

The available commercial systems have some drawbacks, including high costs, reliance on GPS tracker devices, lack of capacity to handle large volumes of data, and lack of integration with advanced 4IR technologies. The author of this study could not find any research that has proposed or developed a holistic and national ICT-based livestock identification and tracking system for controlling livestock theft in South Africa. The current study seeks to fill some of these literature gaps by proposing a solution in the form of an ICT-based model, to explore how stakeholders in South African can utilise ICTs to control livestock theft.

5.12. Summary of Chapter Five

This is the final chapter about the literature review. The main purpose of the chapter was to discuss, evaluate, synthesise and summarise related research and all the aspects related to livestock identification and tracking in the context of livestock theft. To achieve this main purpose, a combination of scoping review method, snowball strategy, PRISMA method, and CASP was adopted. The chapter has addressed some of the study`s research questions, as well identifying gaps in the literature. The findings and gaps obtained in this chapter are fundamental for the sought-after model for controlling livestock theft in country. This is dealt with in chapter eight.

In the context of controlling/mitigating livestock theft, different types of livestock identification methods exist and different types of location tacking technologies, systems, approaches exist as well. Each of the methods, technologies, systems and approaches has its own advantages and disadvantages. The methods, technologies, systems and approaches were evaluated considering the South African context in terms of livestock farming sub-sector situation, and country`s technological, economic, social, and environment situation.

The next chapter deals with the research methodology. The chapter provides a detail account on research paradigm, research approach, research strategy/design, sampling, and data collection methods used in the study.

CHAPTER 6

RESEARCH METHODOLOGY

6.1. Introduction

This research study is guided by both research methodology and development methodology. Research methodology refers to the systematic and step-by-step way of conducting the research process. Research methodology answers four important questions: (i) “what is the approach of the research study: qualitative, quantitative or mixed?”, (ii) “what ethical aspects were taken into consideration”?, (iii)“how was the data gathered?”, and (iv) “how was the data analysed?”. Development methodology answers the important question of “how was the artefact (i.e. model of livestock identification and tracking system) developed?”. This chapter focuses on the research methodology. Development methodology is covered in Chapter Eight.

This chapter presents the type of research, research paradigm, research approach, and research strategy/design that form the underlying basis for the choice of methodology used in conducting this research study. The chapter further deliberates on the sampling methods, research participants, data collection methods, data quality control, and data analysis methods that define the scope of the research study. The last section provides information on ethical considerations that were implemented by the researcher.

6.2. Type of Research

Research is a systematic structured enquiry undertaken to create new knowledge or to solve a specific/practical problem, with the aim of contributing to existing body of knowledge (Kumar, 2018). Researchers and scholars carry out research mainly to establish or confirm facts, reaffirm the results of previous work, solve new or existing problems, support theorems, or develop new theories (Zina, 2013; Kumar, 2010). Drawing from these definitions, research can be generally classified as pure/fundamental or applied (Kumar, 2010; Burns, 2000). Pure/fundamental research involves developing and testing hypothesises and theories; while applied research involves solving a specific or practical problem of an individual, group or society/community that has direct application to the world. The main premise of pure research is to add further knowledge to the actual existing body of knowledge. On the contrary, applied research is intended for practical use (for solving practical problems) or answering certain questions (Kumar, 2018; Kumar, 2010). Table 17 provides a comparison between fundamental/pure research and applied research.

Table 17: Comparison between fundamental/pure research and applied research

BASIS FOR COMPARISON	BASIC RESEARCH	APPLIED RESEARCH
Meaning	Pure research refers to the study that is aimed at expanding the existing base of scientific knowledge.	Applied research is the research that is designed to solve specific practical problems or answer certain questions.
Nature	Theoretical.	Practical.
Utility	Universal.	Limited.
Concerned with	Developing scientific knowledge and predictions	Development of artefact, technology, technique, concept, product, service.
Goal	To add some knowledge to the existing one.	To find out the solution for the problem at hand.

Source: Author`s illustration based on Kumar (2018); Kumar (2010)

Livestock theft is a national and practical problem that has direct/indirect effects to the farmers, government, communities, traditional authority and industries. The purpose of this study is to "address" a specific and practical problem, which is livestock theft in South Africa. To address this specific and practical problem, the study provides a model of a livestock identification and tracking system. The study touches on some general aspects of applied research. This is because the study has correctly identified a very important and persistent problem (i.e. livestock theft), and at the end of the day proposes some thoughts on how livestock theft can be mitigated. The study does this at a conceptual level, understands and packages the problem within the information science domain; but the proposed solution is not implemented/tested in real environment. The study stops at exploring the problem and the context it persists and give thoughts on what SAPS ought to do, falling short of being a purely applied research. Therefore, the type of research suitable for this study is basic research with some elements of applied research.

6.3. Research Paradigm

Research is generally guided by a set of beliefs or a worldview. This set of beliefs or a worldview is known as paradigm (Killam, 2013). Saunders et al. (2007) define research paradigm as a basic set of universally acceptable views that guide and channel the researcher towards the study of the phenomenon. Similarly, Kivunja & Kuyini (2017) define research paradigm as a worldview or high-order way of thinking or logic that underpin all aspects of a research undertaking from the intent/motivation for the research to the final design, conduct and outcomes of the research. The criticality of selecting an appropriate research paradigm is important, because a research paradigm informs the design of a research study, including how either quantitative or qualitative or mixed methods will be used in the research study (Kivunja & Kuyini, 2017). The research paradigms used in conducting research include positivism/post-positivism, interpretivism, constructivism, critical realism, transformative, emancipatory and postcolonial indigenous (Ling & Ling, 2016; Denzin et al., 2006; Chilisa, 2012; Wilson, 2008; Killam, 2013; Saunders et al., 2007; Orlikowski & Baroudi, 1991).

A positivism paradigm typically assumes quantitative methods. The paradigm holds that the scientific method or observations is the only way to establish truth and objective reality. The paradigm generally holds that the methods, techniques and procedures used in the natural sciences offer the best framework for investigating the social world. The most common research strategies employed in a positivism research include experiments and surveys (Killam, 2013; Bryman & Bell, 2011).

A positivism paradigm has been criticised by various scholars such as Smith (2013), Chilisa (2012), Denzin & Lincoln (2011). They argue that the positivism paradigm has marginalised many communities, especially those in Africa, South America and Asia. They further argue that the positivism paradigm has led to the design of research-driven development projects that are irrelevant to the needs of the communities in Africa, Asia and South America. To close the marginalisation gap, other research paradigms known as critical realism, transformative, and emancipatory emerged. The distinctive characteristic of critical realism, transformative, and emancipatory paradigm is that they include critical social science research designs, participatory action research and feminist designs. These paradigms combined aim to emancipate, empower and transform communities through group action. Contrary to other research paradigms, the postcolonial indigenous paradigm holds that research communities/research participants should be involved in identifying the problem, defining the problem, collecting and analysing the data, disseminating the findings and using the findings to inform practice (Chilisa, 2012).

The postcolonial indigenous research paradigm is a worldview that advocates for the non-Western ways of conducting research (Chilisa, 2012). The paradigm holds that there is a need for new ways of conducting research in which the voices of the formerly oppressed generations from silence imposed by colonization can be heard (Chilisa, 2012; Denzin & Lincoln, 2011). The paradigm provides a means for valuing indigenous knowledge systems and philosophies (Chilisa, 2012). Postcolonial indigenous researchers believe that knowledge is relational and shared with all creation (humans, animals, plants, land) (Wilson, 2008). Some of the research methods used in postcolonial indigenous research include storytelling, songs, plays, games, drama, and indigenous knowledge systems in general (Chilisa, 2012).

Contrary to the positivism paradigm, the interpretivism paradigm typically assumes qualitative methods (Killam, 2013; Bryman, 2011). The paradigm holds that knowledge, reality or truth is limited to context, space, time and individuals or group in a given situation and cannot be generalized into one common reality. The interpretivism paradigm aims at understanding people's experiences, perceptions, perspectives, and attitudes. In a research study that follows the interpretivism paradigm, the research questions are generally open-ended, descriptive and non-directional (Killam, 2013). The most common research strategies adopted in interpretivism research include ethnography, phenomenology, biography, case study, and grounded theory (Killam, 2013; Creswell & Poth, 2016).

Interpretivism is a suitable research paradigm for this research study, for various reasons:

- To develop model of a livestock identification and tracking system, the research study sought to gather people`s (livestock stakeholders) experiences, perceptions, views, attitudes on addressing livestock theft through ICT utilization;
- The research study is informed by hermeneutics and phenomenology – that is, the interpretation of people`s (livestock stakeholders) experiences, perceptions, views, attitudes on addressing livestock theft through ICT utilization; rather than quantitatively and statistically analysing them;
- Multiple socially constructed realties – the research study recognises that livestock theft is a societal problem that cannot be addressed by farmers alone. Therefore, the socially constructed realities on addressing livestock theft should be placed on multiple livestock stakeholders (government, farmers, business industry, traditional authority).

6.4. Research Approach (Mode of Inquiry)

A research study can be quantitative or qualitative or mixed (both qualitative and quantitative) in approach (Killam, 2013; Bryma, 2011; Kumar, 2010; Vijay & Arvind, 2010; Burns, 2000). Quantitative approach is concerned with breadth (the measurement of quantity or amount) of the phenomenon under investigation; while qualitative approach is concerned with depth/quality of the phenomenon under investigation (Killam, 2013). One distinctive characteristic of quantitative approach is that it deals primarily with numeric data, and it applies statistical/mathematical interpretations under a reductionist, logical and strictly objective paradigm. Qualitative approach aims at getting the meaning, feeling and description of the situation/phenomenon through the use of nonnumeric information (words/text, images and sounds) and their phenomenological interpretation, which inextricably tie in with human senses and subjectivity. Quantitative approach mainly relies on experiments and surveys for data gathering; while qualitative approach mainly relies on interviews, tapes, researcher`s dairies, and secondary sources (websites, company documents, articles, etc.) for data gathering (Killam, 2013; Bryman, 2011; Kumar, 2010). Table 18 below provides a comparison of research approaches.

Table 18: Comparison of quantitative and qualitative modes of inquiry

ASSUMPTIONS	QUANTITATIVE APPROACH	QUALITATIVE APPROACH
Epistemology	Research is informed by objectivist epistemology.	Research is informed by interpretivism/constructivism epistemology
The nature of reality	There is one reality and the inquiry process can be converged; reality can be manipulated and separated into common parts such as variables.	There is no one reality, as reality consists of interrelated parts that do not necessarily influence other parts of the inquiry; reality is divergent.
The nature of the inquirer-object relationship	There is an independent relationship between the inquirer and objects; detachment and impartiality; objective portrayal; etic (outsider's point of view).	The researcher and the participants depend on each other or there is a relationship between the inquirer and participants and they influence each other; personal involvement and partiality; empathic understanding; emic (insider's point of view).
The nature of truth statement	The belief is that there is absolute truth in the inquiry and an inquiry that is not generalizable is unworthy. Thus, the aims of quantitative inquiry are to develop nomothetic knowledge. Variables can be identified and relationships measured. Inquiry is objective, value-free.	There is no absolute truth and qualitative inquiries are not generalizable. The assumption is that the purpose of inquiry is to develop idiographic knowledge. Variables are complex, interwoven, and difficult to measure. Inquiry is subjective, value-bound.
Purpose	Generalisability (time and context free generalisations through nomothetic or generalised statements); prediction; causal explanations.	Contextualisation (only time and context bound working hypotheses through idiographic statements), interpretation, and understanding actors' perspectives.

Source: Author`s illustration based on Killam (2013); Bryman l (2011); Kumar (2010); Vijay & Arvind (2010); Burns (2000); Krefting (1991)

Most case studies, action research studies and ethnography research studies adopt a qualitative approach (Oates et al., 2022; Creswel & Poth, 2016; Kumar, 2014; Sekaan & Bougie, 2010). A qualitative approach tends to focus on questions of ‘how’ and ‘why’ rather than the quantitative perspective of ‘how many’ or ‘how often’. An interpretive qualitative research approach is a suitable mode of inquiry for this research study for various reasons:

- The researcher is interested in the depth of the phenomenon (livestock-theft) under investigation in its context (South Africa), rather than performing statistical analysis on the phenomenon.
- The researcher is interested in the perceptions, experiences and views of the participants about the phenomenon (livestock-theft).
- The researcher is interested in gaining insight into the phenomenon.
- Qualitative mode of inquiry leads to rich and detailed analysis of a particular phenomenon and its context.
- Interpretive methods allow understanding of a phenomenon through the interpretation of stakeholders' and research participants' experiences.
- Interpretive methods are particularly suitable for explaining the complex socio-technical interaction process by documenting human thoughts, actions, and interactions.

6.5. Research Strategy/Design

Research strategy outlines the way in which research is to be undertaken (Kumar, 2014; Sekaan & Bougie, 2010). Baxter & Jack (2008) define research design as the overall strategy that the researcher chooses to integrate the different components of the research study in a coherent and logical manner. Research design constitutes the blueprint for data gathering methods and data analysis methods. It constitutes the blueprint for systems development methods. This entails analysis, design, implementation and testing of an information system, for example (Oates et al., 2022; Sekaran & Bougie, 2010; Ghauri & Gronhaung, 2010).

Various types of research strategy/design exist; and they include action research, exploratory study, comparative research, explanatory study, experiments, descriptive study, ethnography, and case study (Oates et al., 2022; Creswell & Poth, 2016; Kumar, 2014; Sekaran & Bougie, 2010; Baxter & Jack, 2008). In this research study, a combination of case study and Design Science Research Methodology (DSRM) is adopted as the research strategy/design. The case study strategy/design informs the data gathering methods and data analysis methods, while DSRM strategy informs the development of the proposed system model. The DSRM aims to generate knowledge in the form of artefacts. The artefacts can be models, software, methods, constructs, instantiations, theories or concepts. Data gathering through Interviews, literature review, questionnaires or other methods (e.g. experiments) are used to generate artefacts (Peffers et al., 2007). The DSRM strategy adopted in this research study is covered in chapter eight.

A case study is described as an enquiry of empirical nature that seeks to investigate in detail a contemporary phenomenon chosen in its natural context (Yin, 2012). A case study strategy/design was chosen for the research study for a number of reasons:

- Although livestock theft is prevalent in other countries, the focus of the study is within the South African context.
- A case study in qualitative research provides the ability to capture the experience, reflection and feelings of the subject (Oates et al., 2022).
- A case study strategy/design leads to rich and detailed analysis of a particular phenomenon and its context (Oates et al., 2022). This is inline with the research study`s core theme, wherein livestock-theft is the phenomenon being addressed and South Africa being the context.
- A case study strategy/design leads to the understanding of depth of the phenomenon under investigation in its natural setting, rather than investigating the breadth of the phenomenon in the laboratory or artificial setting (Sekaran & Bougie, 2016; Oates et al., 2022). This characteristic is inline with one of the research study`s objectives: to gain an in-depth understanding of the current situation with regards to livestock identification and tracking, rather than seeking to perform statistical analysis on livestock identification and tracking.
- In a case study strategy/design, the researcher focuses on the complexity of the relationships, and processes and how they are interconnected and interrelated (Oates et al., 2022). One of the research study`s objectives is to understand the role of each stakeholder and relationship between/among stakeholders in dealing with livestock-theft, hence this characteristic is in line with the research study.
- In a case study strategy/design, the researcher uses a wide range of data sources and data gathering methods (Sekaran & Bougie, 2016; Oates et al., 2022). Various sources of data (stakeholders) were chosen as the research participants, and three data gathering methods were used in the research study.

6.6. Sampling

Sampling is a research method used in a research process in which a predetermined number of participants/respondents/informants or observations are selected from a larger population (Trochim et al., 2016). Sampling reduces costs and offers faster data collection, because through sampling the researcher only deals with the sample size rather than including the entire population. Sampling methods/techniques are classified into two types: probability sampling; and non-probability sampling (Surbhi, 2016; Trochim et al., 2016). Trochim et al., 2016 (2016) define probability-sampling method as any method of sampling that utilises some form of random selection in which each participant, respondent, informant or observation has an equal chance of being selected. Nonprobability sampling does not involve random selection, and not all participants, respondents, informants, or observations have equal chances of being selected (Trochim et al., 2016). Table 19 provides a comparison of sampling methods used in research.

Table 19: Differences between probability sampling and non-probability sampling

BASIS FOR COMPARISON	PROBABILITY SAMPLING	NON-PROBABILITY SAMPLING
Meaning	Probability sampling is a sampling technique, in which the subjects of the population get an equal opportunity to be selected as a representative sample.	Nonprobability sampling is a method of sampling wherein, it is not known that which individual from the population will be selected as a sample.
Alternately known as	Random sampling.	Non-random sampling.
Basis of selection	Randomly.	Arbitrarily.
Opportunity of selection	Fixed and known.	Not specified and unknown.
Research	Conclusive.	Exploratory.
Result	Unbiased.	Biased.
Method	Objective.	Subjective.
Inferences	Statistical.	Analytical.
Hypothesis	Tested.	Generated.

Source: Author`s illustration based on Surbhi (2016) and Trochim et al. (2016)

The methods of probability sampling include simple random sampling, stratified sampling cluster sampling, and systematic sampling (Surbhi, 2016; Trochim et al., 2016; Lim & Ting, 2013; Kumar, 2010). They are briefly described and compared in the table below.

Table 20: Probability sampling methods

SAMPLING METHOD	SIMPLIFIED MEANING – SELECTION STRATEGY
Random sampling	'Use random numbers to select participants from a population'
Stratified sampling	'First stratify/group the sample by gender, age, race, etc., then do random sampling'
Cluster sampling	'Divide the population into clusters or units'
Systematic sampling	'Select a sample from a larger population group by selecting every k-th member from a list after starting with a random or arbitrary member.'

Source: Author`s illustration based on Vehovar et al. (2016), and Acharya et al. (2013).

The methods of non-probability sampling include convenience sampling, quota sampling, judgmental or purposive sampling, and snowball sampling (Surbhi, 2016; Trochim et al., 2016; Lim & Ting, 2013; Kumar, 2010; Denscombe, 2007; Coldwell & Herbst, 2004). They are briefly described and compared in the table below.

Table 21: Non-probability sampling methods

SAMPLING METHOD	SIMPLIFIED MEANING – SELECTION STRATEGY
Convenience sampling	'Use who is available'.
Quota sampling	'Keep going until the sample size is reached'.
Judgmental or purposive sampling	'Select the samples based on the preconceived purpose'.
Snowball sampling	'Research participants are asked to assist researchers in identifying other potential subjects'.

Source: Author`s illustration based on Parker at al. (2019), Vehovar et al. (2016), and Acharya et al. (2013).

A purposive and convenience sampling method was adopted for the research study. Coldwell & Herbst (2004) define purposive sampling as a non-probabilistic sample that relates to certain criterion that the researcher wishes to study. Denscombe (2007) states that,

> "with purposive sampling, the sample is 'hand-picked' for the research. The researcher already knows something about specific people, organisations, objects, or events. Then the researcher deliberately selects the particular ones that are likely to produce the valuable data."

Denscombe (2007) further states that

> "the advantages of purposive sampling are economical-oriented in the sense it allows the researcher to focus on objects, people, and events that his/she believes would be critical for the research."

According to Palinkas et al. (2015), a purposive sampling method allows for the identification and selection of knowledgeable research participants in the phenomenon of interest. A purposive and convenient sampling method is adopted for the research study because the researcher is interested in 'livestock-theft' informants and 'ICT' informants. Due to the cost and time factor it is highly impossible to study the entire populations of livestock stakeholders (farmers, relevant government ministries, and traditional authorities) in South Africa. The researcher only limited the sampling to specific livestock stakeholders that have knowledge about livestock theft,

Between 2010 and 2019, the top ten livestock-theft hotspots in the country were Maluti, Mqanduli, Sulenkama, Qumbu, Mthatha, Amangwe, Bulwer, Utrecht, Ladysmith, Bethlehem, and Mount Frere (SAPS, 2019). The years 2017, 2028 and 2019 were the periods when data was gathered by the researcher. Again, because of time factor, the researcher only limited the sampling to the top 10 livestock theft hotspots in the country for these research participants: Traditional Authority, Livestock Farmers, and SAPS`s Stock Theft Units. The livestock-theft hotspots are the areas with the highest incidence of livestock theft, making them the most relevant for studying the effectiveness of any tracking and identification system. The livestock theft-hotspots areas are more likely to have detailed records and reports of theft incidents, providing a rich data for gathering and analysis. The hotspots might exhibit different patterns and methods of livestock theft, allowing for a comprehensive understanding of the various dynamics involved in livestock theft.

6.7. Identification and Selection of Research Participants for the Research Study

To identify the interviewed individuals, their contact details were obtained from the Stock Theft Preventative Forum website and SAPS website. The contact details of farmers and traditional authority were obtained through the members of Stock Theft Preventative Forums. The researcher met some farmers and members of Stock Theft Preventative Forum at the International Conference for Rural Crimes in Centurion, South Africa. The animal production specialists and ICT specialists were identified through searching various relevant websites such as SITA website, CSIR website, ARC website, University websites, TVET college websites, etc. Emails were used and telephones calls were used to recruit the participants and request for their permission to participate in the study.

The purposive and convenience sampling for the study was drawn from the following participants:

Members of the Stock Theft Preventative Form: The Forum constitutes the police, livestock farmers, farmer organisations, legal departments and interested parties. The Forum, through meetings and workshops, discusses matters relating to livestock theft. The Forum has a chairperson in each province. One chairperson from each province was selected as the research participant; therefore, a total of nine participants were selected.

Members of Stock Theft Units from the SAPS: The SAPS`s STUs investigate the reported cases of livestock theft. One personnel responsible for livestock theft cases from each of the 2015 top ten livestock-theft hotspots was selected as the research participants. Therefore, a total of ten participants were selected.

Information systems specialist from State Information Agency (SITA): SITA is a government entity that is responsible for the consolidation and coordination the State's information technology resources to achieve cost savings through scale, increase delivery capabilities and enhance interoperability (SITA, 2020). The SITA is responsible for the implementation of a system known as AIS, which handles the national register of official animal identification marks. One information systems specialist directly involved in AIS implementation was selected from SITA as a research participant. The purpose of selecting IS specialist was mainly to explore the role of ICT in controlling livestock-theft.

Information systems specialist from Council for Scientific and Industrial Research (CSIR): The CSIR is a government entity that undertakes multidisciplinary research and technological innovation that contributes to the improved quality of life of South Africans. One of the research areas is ICTs for agriculture. One information systems specialist from CSIR`s ICTs for agriculture unit was selected as a participant. The purpose of selecting IS specialists was mainly to explore the role of ICTs in controlling livestock-theft.

ICT specialists whose interests lie with ICTs for livestock management: South Africa has public universities that offer information systems as a full-time undergraduate and postgraduate programme. One information systems specialist whose interest lie within ICTs for agriculture from each university in each province (nine provinces in South Africa) was selected as a participant; therefore, a total of nine participants were selected. The purpose of selecting information systems specialist was mainly to explore the role of ICTs in controlling livestock-theft.

Traditional Authority: During the preliminary literature stage, the researcher found that there were some instances when livestock farmers/keepers reported stolen livestock to their local traditional authority (chief, headmen, community leader, etc.). It is for this purpose that traditional authorities were included in this research study. One headmen or community leader from each of the 2015 livestock-theft hotspots was selected as the participant for the research study. Therefore, a total of ten research participants were selected.

Livestock Farmers: One farmer from each of the livestock-theft hotspots was selected as a participant for the research study. Therefore, a total of ten research participants were selected.

Animal production specialists: During the preliminary literature stage, the researcher found that animal production specialists have knowledge about livestock technologies, animal welfare and social issues surrounding livestock. Most animal production specialists are located at the ten South Africa agricultural colleges that offer animal production as a full-time programme. One animal production specialist was selected from each college; therefore, a total of ten animal production specialists were selected as research participants.

National Department of Agriculture: The department`s mandate is to support the livestock sector through laws, policies, programmes, projects, human resources, financial resources and technical resources. The Department is responsible for branding and tattooing of all livestock, preventing stock-theft and control animal disease, as well as promoting animal health. One personnel responsible for the livestock sector from the Department of Agriculture was selected as the research participant.

Agricultural Research Council (ARC): The ARC conducts research with partners, develops human capital and fosters innovation to support and develop the agricultural sector. The ARC, in partnership with SAPS is responsible for livestock DNA forensics of livestock theft related cases. One personnel responsible for the livestock sector from ARC was selected as a research participant.

African Farmers Association of South Africa (AFASA): AFASA aims at developing the competencies of African farmers in order for them to participate meaningfully in formal and informal markets. One personnel responsible for the livestock sector from AFASA was selected as a research participant.

An overall total of 63 research participants were identified and selected to participate in the research study. Table 22 below provides a summary of research participants in relation to purposive and convenience sampling method adopted for this study.

Table 22: Research participants in relation to geographical location and purposive and convenience sampling

Research participants	How many?	Location (geographical diversity of participants).	Justification for purposive and convenience sampling
Members of the Stock Theft Preventative Form.	9	All 9 provinces of South Africa.	Knowledge of livestock theft matters and trends. Time factor was taken into consideration, hence 9 members. The top ten hotspots are the areas with the highest incidence of livestock theft, making them the most relevant for studying the effectiveness of any tracking and identification system.
SAPS`s Stock Theft Units	10	Eastern Cape, KwaZulu-Natal, and Free State.	Livestock theft cases are reported to SAPS. Time factor was taken into consideration, hence 10 members.
Traditional Authority	10	Eastern Cape, KwaZulu-Natal, and Free State.	Some livestock theft cases are reported to the traditional authority. Time factor was taken into consideration, hence 10 research participants.
Livestock Farmers	10	Eastern Cape, KwaZulu-Natal, and Free State.	Famers are the main victims of livestock theft – they are directly affected.
Animal Production Specialists, including ARC and AFASA	12	All 9 provinces.	Knowledge of livestock technologies, livestock sector, animal welfare and social issues surrounding livestock.
IS/ICT specialist from SITA	1	National office in Gauteng province.	Interest in and knowledge about ICTs for agriculture and ICTs for livestock management.
IS/ICT specialist from CSIR	1	National office in Gauteng province.	Interest in and knowledge about ICTs for agriculture and ICTs for livestock management.
Department of Agriculture	1	National office in Gauteng province.	Animal branding and livestock identification.
IS/ICT specialist from universities	9	All 9 provinces of South Africa.	Interest in and knowledge about ICTs for agriculture and ICTs for livestock management.
TOTAL	**63**		

Source: Author`s own illustration

6.8. Data Collection Methods

Data collection is the process by which the researcher collects the information needed to address the research problem, aim or research questions. There are many types of research instruments for gathering data. They include questionnaires, interview schedules/guides, observation guides, scientific experiments, log files, focus group schedules/guides, tally sheets, flow charts, rating scales, aptitude tests, and psychometric devices (Biddix, 2018). The most common data gathering methods used in case study and qualitative research include questionnaires, observations, focus groups, document analysis, secondary sources, and interviewing (Oates et al., 2022; Creswel & Poth, 2016; Kumar, 2014). In this research study, questionnaires and interviews were used as research instruments to solicit empirical-qualitative data from the research participants. The empirical-qualitative data were supplemented by secondary data. Secondary data were gathered through literature analysis and document analysis. The next sub-section describes and justifies the reasons for selecting the data collection methods (questionnaires, interviews and secondary data sources). The sub-section also describes how they were used in the research study.

6.8.1. Questionnaires

A questionnaire offers low-cost and ease of data collection within a short period of time from a large group of people. Questionnaires (Appendices) as data collection instruments were used to solicit data from the Information Systems, ICT specialists and animal production specialists, as identified and selected in section 6.7 above. The questionnaire was sent to the participants through e-mail. Participants were kindly requested to complete the questionnaire and send it back to the researcher through e-mail. An online questionnaire using Google Forms was also created as an alternative.

6.8.2. Interviews

According to Yin (2012), in a case study based on the qualitative approach and interpretivism paradigm, interviews are key to access research participants' experiences, insights and perspectives. Interviews are useful when the researcher wants to gain detailed information on the phenomenon (Oates et al., 2022). Interviews are much used in case studies, ethnography studies and exploratory studies (Creswel & Poth, 2016; Kumar, 2014). Similarly, interviews are much used in research studies that involve DSRM (Oates et al., 2022). This research study is a combination of case study and DSRM by design. In this regard, the researcher sought to gain detailed information on certain aspects. These include the extent and nature of use of livestock identification and tracking systems by the livestock stakeholders and the role of each stakeholder.

Moreover, the research sought in-depth information about the relationship between/among the stakeholders in dealing with livestock-theft in South Africa as well as the role that ICT can play in addressing livestock-theft in South Africa. In addition, the researcher required relevant information from the 'livestock informants' such as farmers, government (police officers and Department of Agriculture) and members of the Stock Theft Preventative Forum. Therefore, interview schedules/guides were used to gather data from the Department of Agriculture, livestock farmers, Stock Theft Preventative Forum, Traditional Authority and members of SAPS`s STUs as identified and selected in section 6.7 above. The interview schedules/guides consist of open-end questions (see Appendices).

6.8.3. Secondary Data Sources

Information related to livestock-theft, and livestock identification and tracking in South Africa was sourced from the South African government websites and Stock Theft Preventative Forum website. Previous research such as journal articles, conference papers, theses and dissertations were used to source information related to livestock-theft in South Africa. Company reports, statistical repositories, websites, news and documents were also used to source information related to livestock-theft, and livestock identification and tracking in South Africa.

6.9. Data Quality Control

Data quality control is an important quality issue in all the critical stages of research (pre-data collection, data collection, analysis, and interpretation of findings). There are two major contesting philosophical worldviews on data quality control, namely: quantitative research-based data quality control, and qualitative research-based data quality control (Bryman, 2006; Golafshani, 2003; Malterud, 2001; Joppe 2000). Positivism research tends to be in favour of quantitative research-based data quality control. In contrast, interpretivism research, transformative research and postcolonial-indigenous research tend to be in favour of qualitative research-based data quality control (Bryman, 2006). Patton & Fund (2002, p.4) state that

> "both qualitative and quantitative researchers need to test and demonstrate that their studies are credible, valid, and reliable". He further states that "validity and reliability are two factors which any researcher should be concerned about while designing a study, analysing results and judging the quality of the study".

Quantitative research commonly uses statistical techniques to analyse data, and is more favoured by the positivist researchers because of its objective nature of enquiry. Reliability analysis and validity are the most common data quality control methods favoured by the positivist researchers

(Bhattacherjee, 2012). From a positivism perspective, according to Joppe (2000), reliability of quantitative research refers to consistency of a measure (exact replicability of the processes and the results). Validity refers to whether the research instrument truly measures that which it was intended to measure or the truthfulness of the research results. To measure reliability of quantitative research, positivist researchers utilise reliability methods such as reliability over time (test-retest reliability), reliability across items (internal consistency), and reliability across different researchers (inter-rater reliability) (Joppe, 2000). In practice, they perform statistical procedures such as correlation test and regression test to measure reliability of quantitative research.

This research study adopted a qualitative approach and interpretivism paradigm. Qualitative research broadly refers to any kind of research that produces findings not arrived at by means of statistical procedures or other means of quantification (Strauss & Corbin, 1998). Qualitative research is more favoured by the interpretivist researchers because of its naturalist approach (Patton & Fund, 2002). Qualitative researchers and interpretivist researchers have a different view when it comes to data quality control. They argue that reliability analysis and validity are not the appropriate methods for judging the quality of qualitative research. Instead, terminology such as credibility, transferability, and trustworthiness should be used when judging the quality of qualitative research (Morgan, 2007; Angen, 2000).

Lincoln & Guba (1994, p.32) agree with many qualitative researchers and interpretivist researchers when they state that

> "while the terms reliability and validity are essential criterion for quality in quantitative paradigms, in qualitative paradigms the terms credibility, neutrality or confirmability, consistency or dependability and applicability or transferability are to be the essential criteria for quality".

Authors such as Macnee & McCabe (2008), Graneheim & Lundman (2004), Holloway & Wheeler (2002), Stenbaacka (2001) and Seale (1999) also agree. For qualitative researchers and interpretivist researchers, to ensure reliability in qualitative research, examination of trustworthiness, transferability, confirmability and dependability is crucial. Table 23 below provides criteria for judging the quality of qualitative research, as an alternative to traditional quantitatively-oriented criteria.

Table 23: Criteria for data quality control

Traditional Criteria for Judging Quantitative Research	Alternative Criteria for Judging Qualitative Research
• Internal validity. • External validity. • Reliability. • Objectivity.	• Credibility. • Transferability. • Dependability. • Confirmability.

Source: Author`s illustration based on Malterud (2001), Lincoln & Guba (1994)

In the context of data quality control, to ensure quality in the research study, the following procedures were undertaken by the researcher:

- **Preliminary literature review:** The researcher conducted an extensive preliminary literature review on livestock theft in South Africa, and livestock identification and tracking systems used around the world. This helped the researcher to gain an insight into the context of the study.
- **Credible literature sources and secondary data sources:** Scholarly databases, government websites and company websites were used to search for relevant literature. Peer-reviewed and reputable sources of literature information such as journal articles, dissertations and theses were used for literature analysis. Credible sources of data such as Statistics South Africa, South Africa Police Services, and Stock Theft Preventative Forum were used.
- **A combination of various review methods**: A combination of Scoping Review Method, snowball strategy, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method, and Critical Appraisal Skill Programme (CASP) was adopted.
- **Conference attendance**: The researcher attended an international conference on rural crimes in Centurion, Gauteng Province, South Africa. This helped the researcher to understand the debates around the subject of "livestock theft, livestock identification and tracking".
- **International Standards Organisations:** All the standards-related information such as RFID standards, livestock registration, and biometric standards was obtained from credible Standards Organisations such as IEEE, WOAH, and ISO.
- **Open-ended questions in the questionnaires and interview guides**: Interview guides and questionnaires were designed to be semi-structured to allow participants to express themselves. This helps minimize biasness and limiting participants to fixed responses.

- **Face-to-face interviews:** Some interviews with participants were conducted face-to-face. This helped improve the trust between the researcher and participants and also provided a greater understanding of participants' context.
- **Peer debriefing and postgraduate committee:** The researcher presented the research study in two colloquium presentations at the University of KwaZulu-Natal (UKZN). The members of academic staff, and the postgraduate committee at UKZN provided the researcher with some critical feedback. The feedback helped the researcher to improve the quality of the research study.
- **Triangulation (multiple sources of data and different research instruments)**: Triangulation involves the use of multiple and different methods, investigators, sources of data, and theories to obtain corroborating evidence (Patton & Fund, 2002). Triangulation helps the investigator to reduce bias, and it cross-examines the integrity of participants' responses (Onwuegbuzie & Leech, 2007; Golafshani, 2003). Data triangulation and informant triangulation were employed in the research study, because the researcher used different sources of data, and two different research instruments.
- **Transferability:** Bitsch (2005), and Tobin and Begley (2004) define transferability as the degree to which the evidence of the research study's findings could be applicable to other contexts, situations, times, and populations. Transferability in qualitative research is synonymous with generalizability (Bitsch, 2005).
- **Purposive Sampling:** Purposive sampling was used in the research study. This allowed the researcher to focus on key informants, who are particularly knowledgeable about livestock theft in South Africa, and ICTs for livestock management.

6.10. Data Analysis – How was Data Analysed?

Data analysis is a process of inspecting, cleansing, coding and transforming data into useful information with the goal of discovering findings, and making conclusions/inferences (Kumar, 2018). The research study is qualitative in approach; therefore, the researcher followed the principles of qualitative data analysis when analysing the data. The principles of qualitative data analysis involve a series of several stages, which include: (i) reading through the data to get a general impression; (ii) identification and extraction of segments, categories, themes, and patterns out of the data; and (iv) presenting the results/findings in a table format, matrix format, descriptive format, and visualisation format (Adu, 2023; Kumar, 2018; Creswell & Poth, 2016). Various types of qualitative data analysis methods exist. They include content analysis, thematic analysis, discourse analysis, narrative analysis, grounded theory, phenomenological analysis, ethnographic analysis, and conservational analysis (Lincoln, 2024). Table 24 below provides a brief summary of various types of qualitative data analysis methods.

In this study, the researcher applied both qualitative content analysis and qualitative thematic analysis. In the qualitative content analysis process, the researcher condensed raw data into categories, using inductive reasoning and careful examination and constant comparison of content (Lincoln, 2024; Adu, 2023). An example of qualitative content analysis applied in this study is table 9 (constraints and challenges faced by SAPS in relation to livestock theft), found in chapter 3. Another example is figure 26 (the attitude and perceptions of research participants towards the use of ICT in dealing with livestock theft in South Africa), found in chapter 7. Other examples of qualitative content analysis used in this study are illustrated in chapters 4, 5, 6 and 7. In the qualitative thematic analysis process, the researcher generated themes from the raw data. This was done through coding the raw data to reduce data down into a summary form. An example of qualitative thematic analysis applied in this study is table 26 (the nature and dynamics of livestock theft in South Africa), found in chapter 7.

Table 24: Various types of qualitative data analysis methods

	Content Analysis	**Thematic Analysis**	**Discourse Analysis**	**Narrative Analysis**	**Grounded Theory**	**Phenomenological Analysis**	**Ethnographic Analysis**
Description	It focuses on the systematic classification of data to identify the key categories within data.	It uses coding and focuses on the search and generation of themes from the gathered data.	It examines how language, context and power relations are used to construct meaning and social realities.	It studies the stories and personal accounts to understand how people make sense of experiences.	It develops a theory grounded in data systematically gathered and analysed.	It explores lived experiences to understand the essence of a phenomenon.	It studies cultures and communities by observing and participating in their daily lives.
When to use it?	It is most appropriate for analysing a lot of written data that needs to be sorted through.	It is most appropriate for analysing a lot of written data that needs to be sorted through.	It is best used in situation like political debates and speeches, or discourse in a social hierarchical setting such as conversations between parents and children.	Stories and personal narratives.	When seeking to develop a theory based on data.	When seeking to understand the essence of lived experiences.	For cultural and social interactions within a community.
Software tools that can be used for data analysis	NVivo, Atlas.ti, MAXQDA, etc.	NVivo, Atlas.ti, MAXQDA, etc.	NVivo, Atlas.ti, MAXQDA, etc.	NVivo, Atlas.ti, MAXQDA, etc.	NVivo, Atlas.ti, MAXQDA, etc.	NVivo, Atlas.ti, MAXQDA, etc.	NVivo, Atlas.ti, MAXQDA, etc.

Source: Author`s illustration based on Lincoln (2024), Adu (2023), and Hart & Achterman (2017).

The NVivo software aided the analysis of data. The NVivo software is a powerful qualitative and mixed methods data analysis software (Lumivero, 2024). The advantage of NVIVO software is it can handle many types of files, such as text, audio, videos, images, etc (Lumivero, 2024; UCT; 2024; Hart & Achterman, 2017). The NVivo software allows researchers to organize, analyse and visualize their data, finding the patterns contained in the data (Adu, 2023; Lumivero, 2023). The researcher adopted a three-phase approach in analysing the data. The phases are described below. The screenshots are provided to indicate evidence of use of NVivo software – i.e. how data was entered into, and analysed on the NVivo software.

6.10.1. Phase 1: Organising Data

The first phase of NVivo software use by the researcher was importing (bringing in) data into the NVIVO software. As show on the menu bar in figure 16 below, the researcher used the 'Import' feature of NVIVO to enter the primary data (interview responses and questionnaire responses) and secondary data into the NVivo software. As show in figure 16 below, the researcher organised the gathered data on the NVivo software into five folders: Interviews, Questionnaires, Literature files - Chapter 3, Literature files - Chapter 4 and Literature files - Chapter 5). The researcher also utilised the 'Notes' and Memo' feature to keep notes and insights linked to the primary data and secondary data.

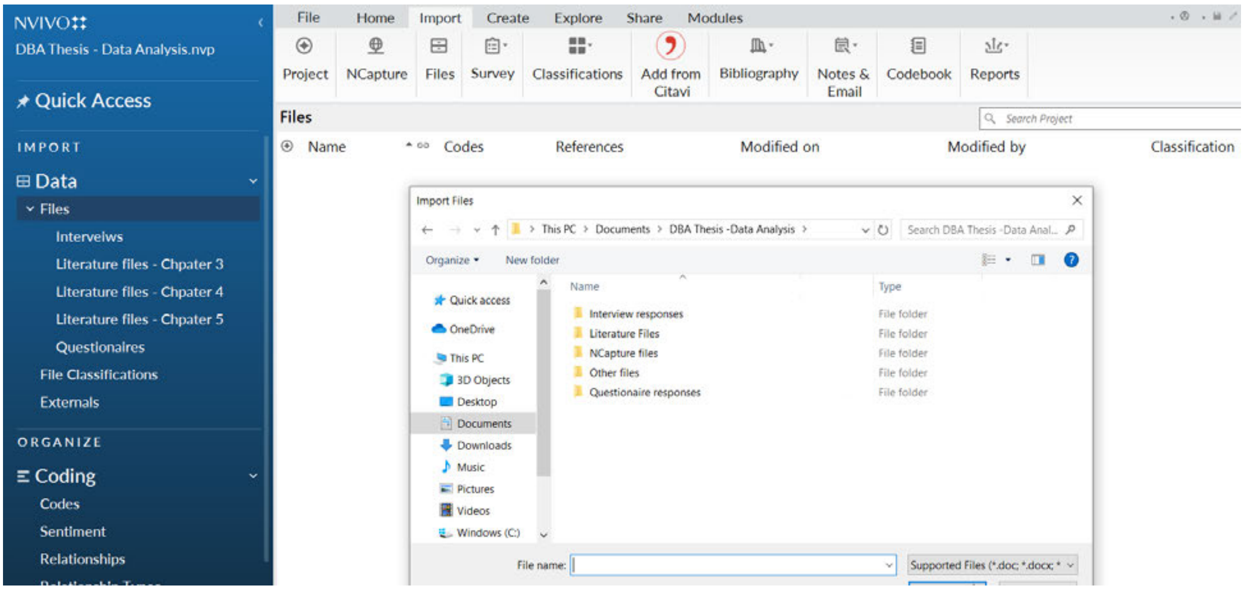


Figure 16: A screenshot of how the researcher used the 'Import' feature of NVIVO software.
Source: Author`s own illustration

6.10.2. Phase 2: Analysing Data

The second phase was the coding process. In NVivo software, coding means bringing together in one place all the references to specific themes, emotions, relationships or people, from the gathered data (Lumivero, 2024). The researcher applied the ‘open coding’ technique. According to Sybing (2024), open codes are created when the researcher examines qualitative data (such as text, images, videos, etc.). The researcher then selects a relevant segment of data, and attaches a code (or codes) that capture the meaning or the aspects that are relevant to the research question within that data segment. In this phase, the researcher used the ‘Code’ feature which is located within the ‘Create’ feature to label some distinct parts of data with codes. For example, the blocks of text show in figure 17 below was assigned the code ‘coordinated livestock theft’, because of its relevance to the nature and dynamics of livestock theft. The researcher also used the ‘Memo’ feature for recording notes, reflections, ideas, and insights during data analysis process.

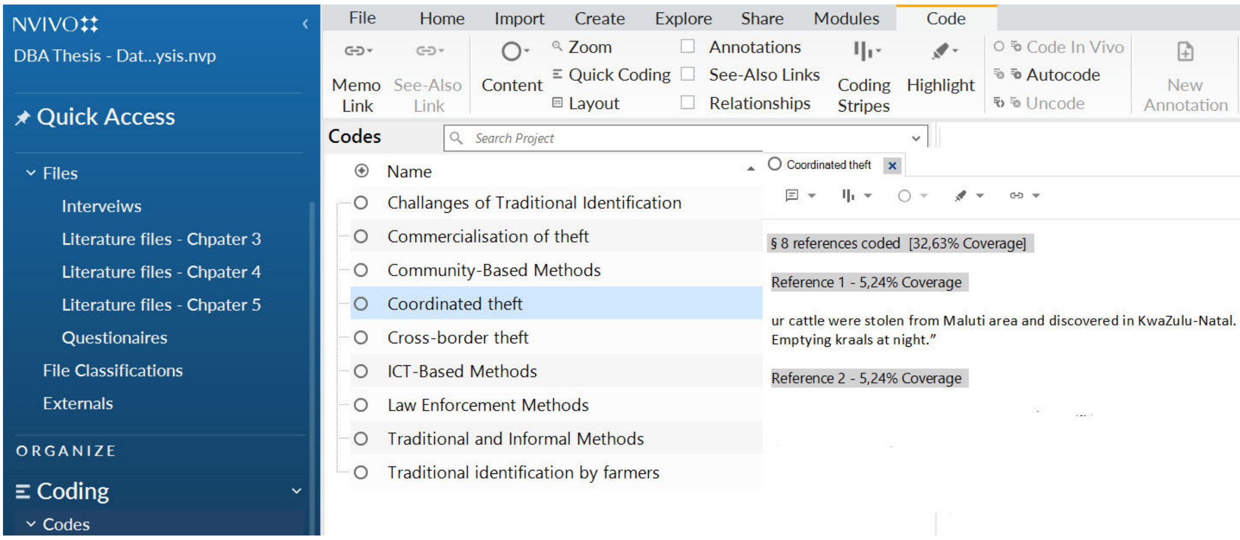


Figure 17: A screenshot of how the researcher used the ‘Code’ feature of NVivo software.
Source: Author`s own illustration

6.10.3. Phase 3: Illustrating and Visualizing Findings and Patterns Contained in the Data

The third phase was the illustration and visualisation of findings and patterns contained in the gathered data. The researcher used the ‘Query’ feature, ‘Text Search’ feature, and ‘Word Frequency’ feature which are located within the ‘Explore’ feature to visualise the findings and patterns contained in the gathered data. The researcher also created tables to illustrate and emphasis the results of the data analysis process. The illustration and visualisation of findings and patterns contained in the gathered data is dealt with in detail in chapter 7.

6.11. Ethical Considerations

According to Zikmund et al. (2013), ethical considerations must be considered by a researcher when investigating phenomena using a case study. In this research study, the researcher implemented the following ethical considerations:

- **Research Proposal:** The researcher presented a research proposal to the academic panel at the University of KwaZulu-Natal (UKZN). The panel approved the research proposal (see approval in Appendix A).
- **Ethical Clearance:** The researcher applied for an ethical clearance to the University of KwaZulu-Natal`s Research Office. The ethical clearance was approved, and granted to the researcher (see ethical clearance in Appendix C).
- **Gatekeeper`s Letter:** The researcher applied for a gatekeeper`s letter to the South African Police Service, National Office. The application was approved, and granted to the researcher (see Gatekeeper`s letter in the Appendix D).
- **Participants` Consent as per UKZN guidelines**: The researcher took into cognisance the guidelines in the UKZN code of conduct for researchers (see Informed Consent in Appendix B).
- **Recognition of Participants:** Recognition was given to all material used and people who participated, as indicated in the references section of this document.
- **Participants' Rights, Anonymity and Confidentiality:** The researcher made telephone calls in advance requesting to interview the participants and the interviewees were made aware of the aim and goal of the study. Participants were informed of their rights, and consent was requested from the interviewees prior to the interviews (as prescribed in the University of KwaZulu-Natal`s consent sheet) (see Appendix C). To comply with the POPIA Act and to protect the privacy of participants, their sensitive information (names, telephone numbers, email address, physical address) are not disclosed in the research study.
- **Progress Report:** The researcher presented the progress report (chapters 1, 2, 3, and preliminary findings – chapter 4) at UKZN College Research Day and received feedback from the participants.
- **Animal Welfare:** Although the research is about livestock, no animal/livestock were used in this research study.
- **Supervisor`s feedback:** The supervisor reviewed the tentative topic, research proposal, research instruments and all the thesis chapters.

- **Sources of Information:** All the sources i.e. books, journal articles, reports, theses, dissertations, interviews held, data from questionnaires, and case studies were acknowledged.

6.12. Summary of Chapter Six

This chapter has provided an overview of the research methodology guiding the research study. The type of research (basic with some elements of applied research) and research paradigm (interpretivism) adopted in the research study were highlighted. The research design was laid out with a description of the strategy (combination of case study and DRSM), approach (qualitative), and methods of data (questionnaires, interviews and secondary sources). The sampling method (purposive and convenient), sample (63 participants) and the actual participants employed in the research study were described in this chapter. The data quality control aspects undertaken for the research study were provided in this chapter. A description of data analysis methods (qualitative approach using thematic analysis and content analysis) used in the research was highlighted. The next chapter provides data presentation, findings, interpretation of findings and discussions.

CHAPTER 7

DATA PRESENTATION, DISCUSSION AND INTERPRETATION OF FINDINGS

7.1. Introduction

The main purpose of this chapter is to provide an illustration and discussion of the outcome of data collected, analysed and interpreted. An illustration of the main findings is presented in descriptive/narrative format, table format, and graphical/visual format. To aid the discussion of the main findings, important commonalities, discrepancies and exceptions in the gathered data are identified and described. This is done by 'connecting', substantiating and reinforcing the study`s findings with the insights, theoretical framework, and existing literature. Because data were gathered from diverse sources, triangulation is also applied in aiding the discussion of the main findings. The purpose of the gathered data was to answer and address the aim, research questions and research objectives of the research study, as established in chapter one. Primary data were gathered by means of questionnaires and interviews. Secondary data were gathered by means of literature sources, as established in chapters three, four and five respectively. In chapter two, it was stated that the theoretical framework would be used as a basis for supporting the data, and the interpretation of the findings. In this regard, this chapter is 'intertwined' with other chapters. Therefore, this chapter can be viewed as an 'integration' of chapters one, two, three, four, five and six, as illustrated in figure 18 below.

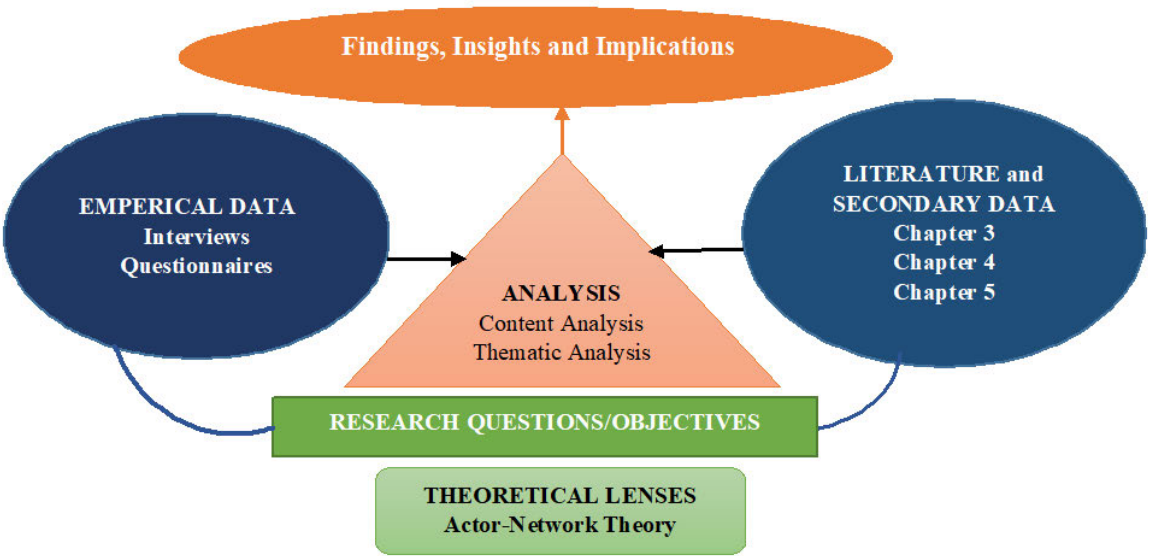


Figure 18: Graphical overview of chapter seven as 'intertwined' with other chapters
Source: Author's conceptualisation of interactive chapters

This chapter is structured as follows: The first section describes the purpose and overview the chapter. The second section contains information on the research participants and how primary (empirical) data were gathered from them. This is followed by data presentation, findings, interpretation and discussions per research question and research objective. The last section summaries the key findings and then concludes the chapter.

7.2. Research Participants and Data Collection Procedures

As already mentioned in the previous section, the empirical data were gathered from the research participants using interview guides/schedules and questionnaires. Key informant interviews were conducted with selected livestock farmers, traditional authorities, members of STPF, and members of SAPS`s STUs. The main purpose of the key informant interviews was to generate insights, perceptions and perspectives from knowledgeable individuals on livestock theft in the country. The purpose was to generate research participants` experiences, attitude, insights perceptions, and perspectives on the role of ICTs for controlling/mitigating/preventing livestock theft in the country. During the interview process, the researcher recorded the responses provided by interviewees, and also developed the notes.

The empirical data were also gathered from the selected animal production, information systems specialists, and ICT specialists using questionnaires. The questionnaires were emailed to the selected participants. An online questionnaire using Google Forms was also created as an alternative. The main purpose was to gather research participants` responses (experiences, attitude, insights perceptions, or perspectives) on the role of ICTs for controlling, mitigating, or preventing livestock theft in the country.

The research participants were diverse in terms of institutions, social structures, geographic location and areas of specializations. Table 25 below shows the research participants, and response rate. A brief description of the profile of research participants is provided in each sub-section following table 25.

Table 25: Response rate by research participants

Participants	Number of Participants Responded	Institution/Structure	Targeted Sample	Data collection methods used
Livestock Farmers	10	Livestock Farming Sector.	10	Interviews
Chairperson	6	Stock Theft Preventative Forum.	9	
Members of Stock Theft Unit	8	Stock Theft Unit – South African Police Service.	10	
Headmen	10	Traditional Authority.	10	
Animal Production Specialists/Professionals	6	Agricultural Colleges.	10	Questionnaires
	1	African Farmers Association of South Africa.	1	
	1	Agricultural Research Council.	1	
	0	Department of Agriculture.	1	
Information system specialists and ICT specialists	1	State Information Technology Agency.	1	
	0	Council for Scientific and Industrial Research.	1	
	6	Universities.	9	
TOTAL	**49**		**63**	
RESPONSE RATE	**49/63*100 = 78%**			

7.2.1. Livestock Farmers

An interview schedule as a research instrument was used to interview the livestock farmers. There were ten livestock farmers who participated in the research study; of which two of them were commercial farmers and the rest were communal farmers. In terms of livestock holding, all the farmers indicated that they were cattle holders. Some communal farmers stated that they also own sheep and goats. The geographical distribution of farmers was diverse. Five communal farmers were based in the Eastern Cape, two were based in Limpopo and one was based in KwaZulu-Natal. One commercial livestock farmer was based in Free State and one was based in KwaZulu-Natal. All the interviewed livestock farmers mentioned that they had been keeping livestock for more than seven years. They all noted their awareness of livestock theft and the impact thereof.

7.2.2. Members of Stock Theft Preventative Forum

Out of a target sample of nine members of STPF, six members were available for interviews. Five of the members were chairpersons of their respective provinces; namely the Eastern Cape, KwaZulu-Natal, Northern Cape, Free State, and Mpumalanga provinces. The sixth interviewee from the STPF was the national chairperson of the Forum. All the members stated that they had been with the Forum for more than three years. In terms of areas of specialisation, the interviewed members of the Forum had diverse interests, including Law, Agriculture, and Criminology. All of these interviewees had extensive knowledge on livestock theft, and the impact thereof.

7.2.3. Members of SAPS`s Stock Theft Units

Out of a targeted sample of ten members of SAPS`s Stock Theft Unit from the top ten livestock-theft hotspots in South Africa (Maluti, Sulenkama, Qumbu, Mthatha, Amangwe, Bulwer, Utrecht, Ladysmith, Bethlehem, Mount Frere), eight were available to be interviewed. All the interviewed members of SAPS` Stock Theft Unit stated that their roles involved the investigations of livestock theft reported cases in their respective regions. All the members of SAPS` Stock Theft Unit had more than four years of experience working for the unit.

7.2.4. Traditional Authority

There were ten headmen (members of the traditional authority) who participated in the research study. Out of the ten interviewed headmen, six stated that they have had cases of livestock theft reported to them by the farmers and community members. When it comes to dealing with livestock-theft cases, some headmen mentioned that they liaise with community forums, members of the farming community and the police. All the interviewed headmen stated they were aware of livestock-theft and the impact thereof.

7.2.5. Animal Production Specialists/Professionals

A questionnaire, as a research instrument was used to gather data from the animal production specialists/professionals. The target sample of Animal Production Specialists/Professionals consisted of thirteen participants. Specifically, ten participants from agricultural colleges, one from African Farmers Association of South Africa, and one from Agricultural Research Council were sought after by the researcher. Out of ten participants from the agricultural colleges, six participants completed the questionnaires. The participant from African Farmers Association of South Africa, one from Agricultural Research Council, and one from the Department of Agriculture chose to be interviewed. The participant from the Department of Agriculture stated that the Department of Agriculture does not directly deal with livestock-theft cases, and he referred the researcher to the SAPS.

7.2.6. ICT Specialists and Information Systems Specialists

A questionnaire, as a research instrument was used to gather data from the ICT specialists and IS specialists. Out of a target sample of eleven research participants, seven research participants completed the questionnaire. There were six research participants from the academic sector, and one from the government sector who completed the questionnaire. These respondents had diverse interests and expertise, including Artificial Intelligence, Cybersecurity, Big Data and Analytics, Software Management, and Software Development. All of them indicated that they had more than ten years of experience in the ICT domain.

7.3. Findings, Interpretation and Discussions

This section deals with data presentation, findings, interpretation and discussions per research question and research objective. The sub-sections under this section are organised using the research questions outlined in chapter one. Where applicable, an example of data analysis process using sample quotes and content from the gathered data is illustrated in a table. In this regard, the data analysis process involved identifying and labelling codes/nodes, categories, and themes. In the context of this research study, the definition of the terms ‘codes/nodes’, ‘categories’, and ‘themes’ is borrowed from Saldana (2013). A code/node refers to a word or phrase which represents a single idea. A category refers to a word or phrase to describe a group of codes/nodes. A theme refers to a word or phrase to describe a broader and overarching idea (Saldana, 2013). Figures are also used to illustrate a summary of the key findings.

In chapter six, it was discussed and justified that this research study is qualitative in approach and underpinned by the interpretivism paradigm. According to Walsham & Sahay (2006), the interpretivism paradigm and qualitative approach allow for the understanding of a phenomenon through the interpretation of stakeholders’ and research participants’ experiences, perceptions, perspectives, insights, views and opinions. According to Walsham & Sahay (2006), and Klein & Myers (1999) the interpretivism paradigm and qualitative approach are particularly suitable for explaining the complex socio-technical processes of actors by ‘mapping’ their actions, relations and interactions. It is for this purpose that ANT was adopted as the theoretical framework to support data presentation, findings, interpretation and discussions in this chapter.

7.3.1. Research Question One

This sub-section presents evidence of the manner in which the first research question was answered. The posed research question is: "How does livestock theft occur in South Africa?". To explore how livestock stakeholders can use ICTs to control livestock theft in South Africa and then propose a model of a livestock identification and tracking system, it is important to first understand how livestock occurs in the South African context. Thus, from both an empirical data perspective and a secondary data perspective, the main purpose of this research question and objective was to uncover the nature and dynamics of livestock theft in the country.

The researcher used the 'Word Cloud' feature of NVivo to explore a graphical representations of word frequency related to research question 1. Word clouds are useful for previewing a text for important characters, themes, and phrases. Figure19 below is a word cloud to depict the visual representation of primary data and secondary data, regarding research question 1. The figure shows that much emphasis has been placed on the words such as South Africa-Lesotho, night, syndicates, rebranding, actors, undocumented, money, fake, etc.

Figure 19: Word Cloud used to address research question 1
Source: Researcher's analysis of primary and secondary data: Research Question 1

The researcher also used the 'Word Tree' feature of NVivo to explore how the word syndicate was used in the gathered data. This is depicted in figure 20 below.

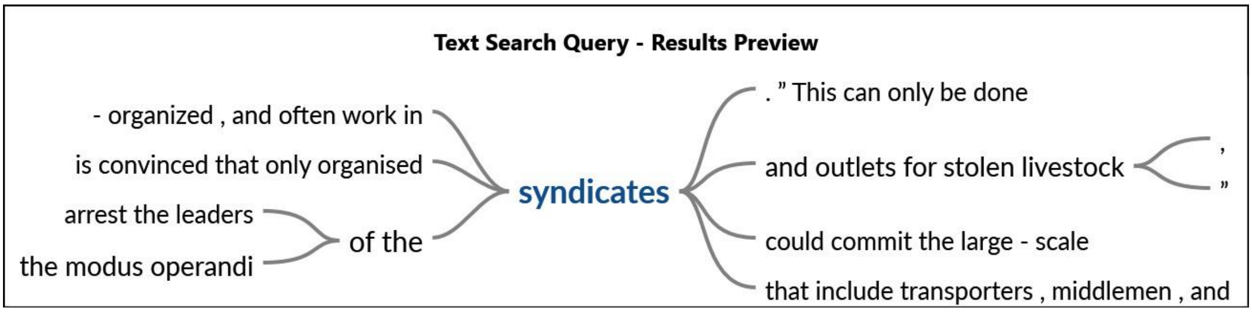


Figure 20: Word Tree used to address research question 1
Source: Researcher's analysis of primary and secondary data: Research Question 1

Based upon the exploration of word clouds, word tree, text search and text query using the NVivo software, the researcher coded the data. From the gathered data and through the actor identification and mapping, it became evident that livestock theft in the country is of the coordinated, commercialized, organized and cross-border nature, as illustrated figure 21 below. This figure shows an overview of the coded themes from the gathered data using NVivo software. The detailed results of data analysis process 'linked' to figure 21 are illustrated in table 26 below.

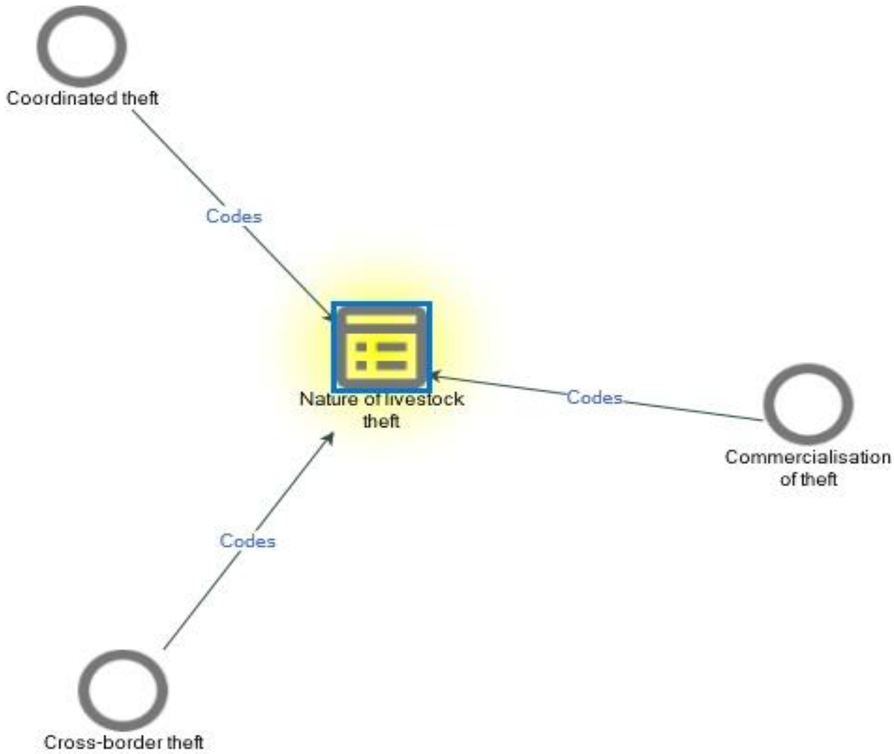


Figure 21: Themes connected to the nature of livestock theft in South Africa
Source: Researcher's analysis of primary and secondary data using NVivo: Research Question 1

The nature of livestock theft in the country is characterized by networks of national and international actors. Lesotho is among the 'top' destinations where stolen livestock from South Africa are disposed. Stolen livestock from Lesotho are being disposed in South Africa as well.

Hence, there are cases whereby livestock are stolen from one province and end being disposed in another province within the country. These findings are consistent with Pasiwe et al. (2021), Doorewaard (2020), Chelin (2019), Visible Policing (2019), Chelin (2019), Maluleke & Dlamini (2019), Maluleke (2018), Clack & Minnaar (2018), Muller (2016), and Clack (2015), as established in chapter four. A coordinated, commercialized and an organized livestock theft typically involves a number of actors. These are: the organizers ("so-called masterminds"), perpetrators (so-called runners) who directly commit the theft of farm animals. The assistant tipper-off (accomplice) informs the previous mentioned actors about "easy prey". Then there are general assistants, and couriers (Aiyzhy et al., 2021).

The nature of livestock theft in the country requires a collaborative effort involving various actors. In chapter five, various relevant ICTs that can be used to mitigate livestock theft were discussed and examined. Some of these ICTs include GPS, RFID, surveillance systems, mobile applications, alert systems, data analytics, cloud computing, biometric identification systems, and digital campaigns. The utilisation of ICTs can play a crucial role in combating livestock theft, especially when it is coordinated, commercialized, organized, and cross-border in nature. These ideas are supported by Aiyzhy et al. (2021), Clack (2020), Visible Policing (2019), Centre for Democracy and Development (2018), Bunei (2017), Stock Theft Preventive Forum (2015), and PMG (2010). According to Bunei (2017), implementing ICT solutions to mitigate livestock theft requires collaboration between farmers, technology providers, law enforcement agencies, and governments. The integration of ICTs can significantly reduce livestock theft and improve recovery rates for stolen livestock. Hence, there is a need for a comprehensive and national ICT-based livestock identification and tracking system to control livestock theft in the country. This is elaborated on in chapter eight.

Table 26: The nature and dynamics of livestock theft in South Africa

Sample Quote / Content	Source of Quote/Content	Codes/Nodes	Categories	Themes
"The Maluti region around the Lesotho-South Africa border is rife of conflicts and violence due to livestock theft".	Interviews.	South Africa-Lesotho	Consequences of livestock theft.	Cross-border theft.
"Thieves smuggle livestock from South Africa into Lesotho and from Lesotho into South Africa."	Interviews.	South Africa-Lesotho	Modus operandi.	Cross-border theft.
"Four cattle were stolen from Maluti area and discovered in KwaZulu-Natal."	Interviews.	Two distant regions	Group of animals.	Coordinated theft
"Emptying kraals at night."	Secondary data.	Planned time occurrence	Sophisticated tactics.	Coordinated theft
"60 cattle were stolen by the perpetrators. They bent the gates. They cut the padlocks with cutters."	Secondary data.	Use of equipment.	Group of animals.	Coordinated theft.
"Livestock were stolen at grazing camp and some at kraal within household during the night."	Secondary data.	Planned time occurrence.	Group of animals.	Coordinated theft.
"Livestock were stolen from grazing camp during the daytime and slaughtered in the absence herdsman."	Secondary data.	Absence of the guardian.	Group of animals.	Coordinated theft.
"Stolen sheep from Lesotho were recovered in South Africa."	Interviews.	Lesotho-South Africa.	Group of animals.	Cross-border theft.
"Stolen cattle from the Eastern Cape, and recovered in Gauteng."	Interviews.	Two distant regions.	Group of animals.	Coordinated theft.
"Some see livestock theft as a way of making quick money."	Interviews.	Market.	Group of people (thieves, buyers and sellers).	Commercialisation.
"Livestock stolen, then rebranded and brought back into supply chain."	Secondary data.	Ineffective identification methods.	Sophisticated tactics.	Coordinated theft.
"Use of transportation such as cars, and trucks."	Secondary data.	Access to transport.	Sophisticated tactics.	Coordinated theft.
"Use of weapons, branding equipment and fake documentation."	Secondary data.	Access to tools.	Sophisticated tactics.	Coordinated theft.
"Collusion among various actors such as farmers, farmer workers, livestock thieves, drug cartels, buyers, law	Secondary data.	Various actors.	Collaboration of a group of people.	Commercialisation.

Sample Quote / Content	Source of Quote/Content	Codes/Nodes	Categories	Themes
enforcement officers, and foreign nationals."				
"Youths from Botswana colluded with youth from South Africa to steal livestock and sell it for drug money/"	Secondary data.	South Africa-Botswana.	Collaboration of a group of people.	Cross-border theft.
"Livestock thieves from South Africa were collaborating with their counterparts from neighbouring Lesotho with whom they exchanged stolen livestock."	Secondary data.	Lesotho-South Africa.	Collaboration of a group of people.	Cross-border theft.

Source: Researcher's analysis of primary and secondary data: Research Question 1

7.3.2. Research Questions Two and Three

This sub-section seeks to answer the research questions numbered two and three respectively. Research question two and research question three are 'intertwined', hence they are analysed together in this sub-section. To explore how livestock stakeholders can use ICTs to control livestock theft in South Africa and then propose a model of a livestock identification and tracking system, it is important to identify the important South African human actors involved 'in the fight against' livestock theft. It is important to 'map' their roles, interests, relations, and interactions. It is important to address the question of 'who', 'what' and 'how' in dealing with livestock theft in South Africa. Thus, from both an empirical data perspective and a secondary data perspective, the main purpose of this research question was to explore the important human actors to include in the livestock identification and tracking system and determine how they are organised for controlling livestock theft in the country.

The majority of research studies and journal articles on ICTs and livestock theft that were found in the literature mainly focused on farmers as the key stakeholders in dealing with livestock theft. This research study took a holistic approach to explore the various stakeholders (actors), their roles (actions) and interactions/relations (networks) in dealing with (addressing) livestock theft in the country. As already stated in chapter three, it is for this purpose that ANT was adopted as the theoretical framework to support data presentation, interpretation of findings and discussions of findings in this chapter.

Research participants expressed their views, perceptions, insights and perspectives on the role that can be played by traditional authorities, police, government, industry players, and livestock farmers in dealing with (addressing) livestock theft in the country. Key non-human (technological) actors identified are database, unique identification method, ICT platform (software, hardware, and connectivity), social media, website, intelligence data, and social media groups. Key human actors identified are farming communities, rural safety officials, headmen, farmers, police, herdsmen, livestock keepers, STUs, Department of Agriculture, abattoirs, auctioneers, farmers, Government, slaughterhouses, and law enforcement agencies. Equally, cattle and livestock were also identified as actors.

Research participants suggested various forms/types of 'actor-network' among the identified actors. The suggested forms/types of 'actor-network' include community linkages, collaborations, coordination, effective relations and communications, livestock movement control, social networking, registration of livestock, information exchange platform, and some forms of livestock verifications. For instance, one ICT specialist states that: *"Farming* *communities can group themselves to create common identities and markings of cattle in addition to individual identification to make their animals easily recognizable"*. Similarly, one animal production specialist says that: "*Communities need to work hand-in-hand and report cases of livestock theft"*. This suggestion about collaboration is consistent with Bunei (2017), and Clack (2015) when they asserted that for livestock theft to be strategically addressed through ICTs, and all role players (law enforcement agencies, communities, farmers, slaughterhouses, etc.) need to be actively involved. Similarly, the findings on social networking and information exchange platforms are consistent with Nunns et al. (2022), Krishnan et al. (2022), Cognac (2018), Bunei (2017) and Clack (2015). This suggest that social media platforms can play a role in the spread of information related to livestock theft incidences, including sharing news, updates, or warnings about thefts. This could contribute to community awareness and response against livestock theft.

The findings on community linkages are consistent with findings obtained by Nunns et al. (2022) in Europe and North America. Bunei (2017) and Clack (2015) suggested similar actor-networks for the African context. Similarly, Krishnan et al. (2022) suggested community mobilisations. Dial Direct (2017) reported a similar initiative. This consistency across studies suggest the importance of establishing linkages and collaborations among various actors in their communities to control, mitigate or address incidents of livestock theft. The idea is to leverage the collective efforts and resources of the community to facilitate liaison among actors for community updates, crime updates and information sharing (Nunns et al., 2022; Cognac, 2018). The community linkages can be initiated and implemented through ICTs.

The findings on livestock verifications, livestock movement control, and registration of livestock align with previous research in the context of animal biometric technology (Kumar, 2018; Awad, 2016; Jain et al., 2014; Barron et al., 2009; Allen, et al., 2008; & Barry et al., 2011). This consistency suggests the effectiveness or relevance of employing animal biometric technology for livestock management and registration to livestock theft control/mitigation. In the literature, several authors pointed out that implementing livestock verification and registration through animal biometric technology could contribute to the overall security of livestock, discourage theft, and provide a legal framework for addressing instances of livestock theft when they occur (Kumar & Singh, 2020; Kumar, 2018; Barron et al., 2009). To design, implement and deploy a livestock verification and registration system, Kumar & Singh (2020) recommended a retinal pattern-based animal biometric system. Kumar & Singh (2020) pointed out that such a system can be widely deployed across an extensive variety of individual animals like cattle, sheep and goats.

According to Diaz & Urquhart (2010), the concept of translation is central in ANT. This concept guides the construction of a complex socio-technical network of actors through its four phases, as described in chapter two. For the phases of translation to be realized, a stable and sustainable 'actor-network' needs to be established, as one research participant suggests: *"Police can maintain a list of missing livestock and work with establishments like abattoirs and auctioneers to stop possible sales of stolen animals. Enforce a registration system for all farmers to use, where all animals would be marked accordingly. Government may force people who slaughter cattle to provide details and the origins of the livestock to the police, that would help police notice livestock that are reported missing or stolen".* This information suggests that livestock theft cannot be resolved (addressed) by farmers only or police alone; a multi-stakeholder approach constituting various actors in needed.

For the 'actor-network' to be stable, the role of traditional authorities is important in the farming communities, because most of livestock farming practices take place in the rural areas. From a theoretical perspective, Muller (2017) emphasises the importance of the ANT translation process in which actors and actants come together, interact to form an actor-network. Muller (2017) further points out the translation of technology and practices into the actor-network. Research participants were of the view that traditional authorities can serve as a link between government and farming communities. For instance, one ICT specialist points out that "*Headmen can help communities group themselves to be able to identify animals belonging to other members of the same community and liaise with other authorities and government to verify transactions relating to stock".* Similarly, one animal production specialist says *"traditional authority can help establish community based institutions and processes to monitor livestock movement, sales, and transfers".* Another ICT specialist had a similar a view when he stated that *"Traditional Authority can organise systems to register stock, maintain and identify stock details linked to owners' details"*. In the literature, there are many discrepancies and exceptions regarding traditional authorities for controlling livestock theft. Research in this aspect (traditional authorities) has received less attention. In the literature, the role of traditional authorities is overlooked. Stock Theft Preventative Forum (2015) pointed out the traditional authorities are important actors for controlling livestock theft, since some cases of livestock are to reported to them by farmers.

Since livestock stakeholders are situated in distances far apart from each other, the socio-technical alliance of actors can be realized through ICTs. As expressed by one ICT specialist*: "All stakeholders could participate in an up-to-date electronic system that associates owners and their animals and their operations"*. Similarly, another ICT specialist states that *"Government can* *work together with farmers by training farmers on ICT techniques and providing the necessary support. Smart livestock farming through IoT may solve the problem of livestock theft"*. This finding aligns with the broader literature on the use of ICTs in livestock management for controlling livestock theft, particularly the implementation of IoT. The finding is consistent with Farooq et al. (2022), Akhigbe et al. (2021), Indonesia, Imtihan et al. (2021), Joshitha et al. (2021), Priyanka (2019), Maluleke (2018), Stojkoska et al. (2018), Saravanan & Saraniya (2018), Abdullahi et al. (2019), Dieng et al. (2017) and Wamuyu (2017). The finding and consistency with the literature emphasise the importance of collaboration and interaction between social and technical elements to achieve a common goal (i.e. controlling livestock theft).

In chapter five, the analysis of content from the online documents, websites and journal articles revealed that the STUs, farmers (victims of livestock theft), and the STPF are the main actors in dealing with livestock theft in South Africa. The roles of these important actors are clearly defined. However, what is surprising is the lack of local (rural and farm level) STPFs and visibility of STPF on the 'ground level' closer to the farms in the rural areas. The STPF operate from provincial and national level. On the other 'side', several authors reported lack of trust of police among livestock farmers. Hence some livestock farmers tend not to report stolen livestock to the police, as established in chapter three. While some communal livestock farmers report stolen livestock to the traditional authorities (headmen, chiefs, etc.), the roles of traditional authorities in dealing with livestock theft is not clearly defined, specified, or stipulated in the government documents.

Municipal councillors operate on the 'ground level' closer to the farming communities in the rural areas. Some local municipalities have agricultural entities that have some sort of linkages with farming communities. However, the role of local municipal actors is not clearly defined, specified, or stipulated in dealing with livestock theft in South Africa. In the literature, there is no mention of the role municipal agricultural entities play in assisting with controlling livestock theft. In chapter Three, it was established that other relevant and important actors in the 'fight against' livestock theft include CPSs, SANDF, Crime Intelligence Department, COGTA, and Houses of Traditional Leaders. However, in the literature these actors are under researched. In Chapter Four, it was established that role of DALRRD is to enforce branding and tattooing of all livestock in the country. Despite this, the various actors within DALRRD such as extension officers and animal technicians, seem to be underutilised in dealing with livestock theft in the country.

In Chapter Three, it was established that some of the adopted forms of ICTs in the country include mobile phones, radio and TV. Despite this significant development, there seems to be a lack of information exchange about livestock theft among the actors via ICTs. There seems to be lack of information dissemination on matters related to livestock theft dissemination via mobile technology, radio and TV. There seems to be a lack of coordinated community linkages via ICTs. This argument is supported by the responses obtained from the research participants. For instance, one farmer says that "*Stock theft is rarely broadcast on radio and social media*". A member of STPF highlights that "*There is not much use of technology in addressing this problem. I think technology can play a role"*. Similarly, a member of STUs states, *"The only technology we use in dealing with stock theft is phones when we want to call the victims".* There is a substantial body of literature on the use of GSM technology, mobile-enabled products and services, and herd management apps in the context of controlling or mitigating livestock theft (Kriel, 2020; Sirotek & Hart, 2019, Stojkoska et al., 2018; Uys, 2017; Katamba & Mutebi, 2017). However, the literature points out a notable gap in research regarding the use of radio and TV for the same purpose. Table 27 below shows the results of the data analysis process.

Table 27: Key human actors and non-human actors for livestock identification and tracking in the South African context

Sample Quote/Content	Source of Quote/Content	Codes/Nodes	Categories	Theme
"Farming communities can group themselves to create common identities and markings of cattle in addition to individual identification to make their animals easily recognizable".	Questionnaire.	Community based actors	Network: Community linkages.	Actor-Network: database, unique identification, cattle, communities.
"All stakeholders could participate in an up-to-date electronic system that associates owners and their animals and their operations".	Questionnaire.	Active and diverse actors	Network: Livestock verification.	Actor-Network: database, animals, people, unique identification.
Headmen can help communities group themselves to be able to identify animals belonging to other members of the same community and liaise with other authorities and government to verify transactions relating to stock".	Questionnaire.	The role of traditional authorities as actors.	Network: Community linkages.	Actor-Network: Headmen, farming communities, identification, verification, transactions.
"There is a need for a platform from which livestock owners can share information with all relevant police sections that are in line with their needs".	Secondary data.	The importance of relations and interactions between Farmers and Police.	Network: Information exchange platform.	Actor-Network: Farmers, Police, ICT platform (software and hardware, connectivity).
Traditional authority can help establish community based institutions and processes to monitor livestock movement, sales, and transfers".	Questionnaire.	The role of traditional authorities as actors.	Network: Community linkages.	Actor-Network: Traditional authority, communities, livestock.
"The Department of Agriculture needs to be included, since they are responsible for the registration of identification marks."	Secondary data.	The role of government as actors.	Network: Registration of livestock.	Actor-Network: Department of Agriculture, registration, unique identification.
"Police can maintain a list of missing livestock and work with establishments like abattoirs and auctioneers to stop possible sales of stolen animals. Enforce a registration system for all farmers to	Questionnaire.	The importance of diverse actors.	Network: Registration of livestock.	Actor-Network: Police, Abattoirs, Auctioneers, Farmers,

Sample Quote/Content	Source of Quote/Content	Codes/Nodes	Categories	Theme
use, where all animals would be marked accordingly."				
"Government may force people who slaughter cattle to provide details and the origins of the livestock to the Police, that would help Police notice livestock that are reported missing or stolen".	Questionnaire.	The importance of enforcement among actors	Network: Livestock movement control.	Actor-Network: Government, slaughterhouses, Police, livestock.
"We would like to have strong ties with rural safety officials and the stock-theft unit. Livestock owners have been appealing for relations with the Police."	Secondary data.	The important of relationships between Actors	Network: Effective relations and communications.	Actor-Network: Rural safety officials, livestock, stock-theft unit, livestock owners.
"Farmers should be empowered and encouraged to register with social media technologies. One example in Kenya is tweeting chief who has been able to combat crimes including stock theft. We should also think of creating a website to enable all law enforcement agencies to contribute intelligence data. These simple messages that are instantly uploaded to many".	Secondary data.	Social actors.	Network: Social networking.	Actor-Network: Farmers, registration, social media, website, enforcement agencies, intelligence data.
"People at the same time can raise alert to people of stock theft that has occurred. This social media groups should also incorporate slaughterhouse personnel, police, local administrators etc."	Secondary data.	Social actors.	Network: Social networking.	Actor-Network: Police, slaughterhouses, traditional authorities, social media groups.

Source: Researcher's analysis of primary and secondary data: Research Questions 2 and 3 respectively.

Based upon the identified key non-human actors and human actors, the researcher created a sociogram, as illustrated in figure 22 below. In a qualitative research that adopts an ANT, a sociogram is a visual model that can be used to illustrate how different individuals, groups or entities are connected (Contandriopoulos et al., 2017). In this context, the sociogram in figure … was created to illustrate how various stakeholders and technologies can interact to control livestock theft. The sociogram seeks to map out the relationships and interactions among various stakeholders and the suggested measures/technologies to control livestock theft. The sociogram highlights the interconnected relationships and collaborative efforts required to effectively combat livestock theft using ICTs.

In the sociogram depicted in figure 22 below, the blue nodes indicate human actors. The green nodes indicate non-human actors (technologies), while the red notes indicate livestock. The edges represent the suggested relationships and interactions among these actors, such as collaboration, coordination, information exchange, and livestock verification. This sociogram provides a comprehensive view of the complex network of actors that could be involved in combating livestock theft, emphasizing the importance of a multi-stakeholder approach and the integration of both human and technological elements.

- Collaboration: All actors can collaborate to effectively address livestock theft.
- Information sharing: Information exchange is crucial (e.g. reporting of stolen livestock). This can be done through ICT platforms to facilitate communication between farmers, rural safety officials, and government agencies.
- Community linkages: Building strong connections within communities is essential. This can be possible when traditional authorities, headmen, and municipal councilors connect with farming communities to establish systems for livestock identification and movement control.
- Livestock management: Registration, movement control, and verification of livestock are important. The Department of Agriculture and Government can enforce livestock branding, tattooing, and registration using unique identification methods and databases.
- Coordination: Police, STUs, and law enforcement agencies can work with abattoirs, auctioneers, and slaughterhouses to track livestock and prevent the sale of stolen animals.
- ICT integration: Technology can facilitate communication, data storage, identification and tracking.

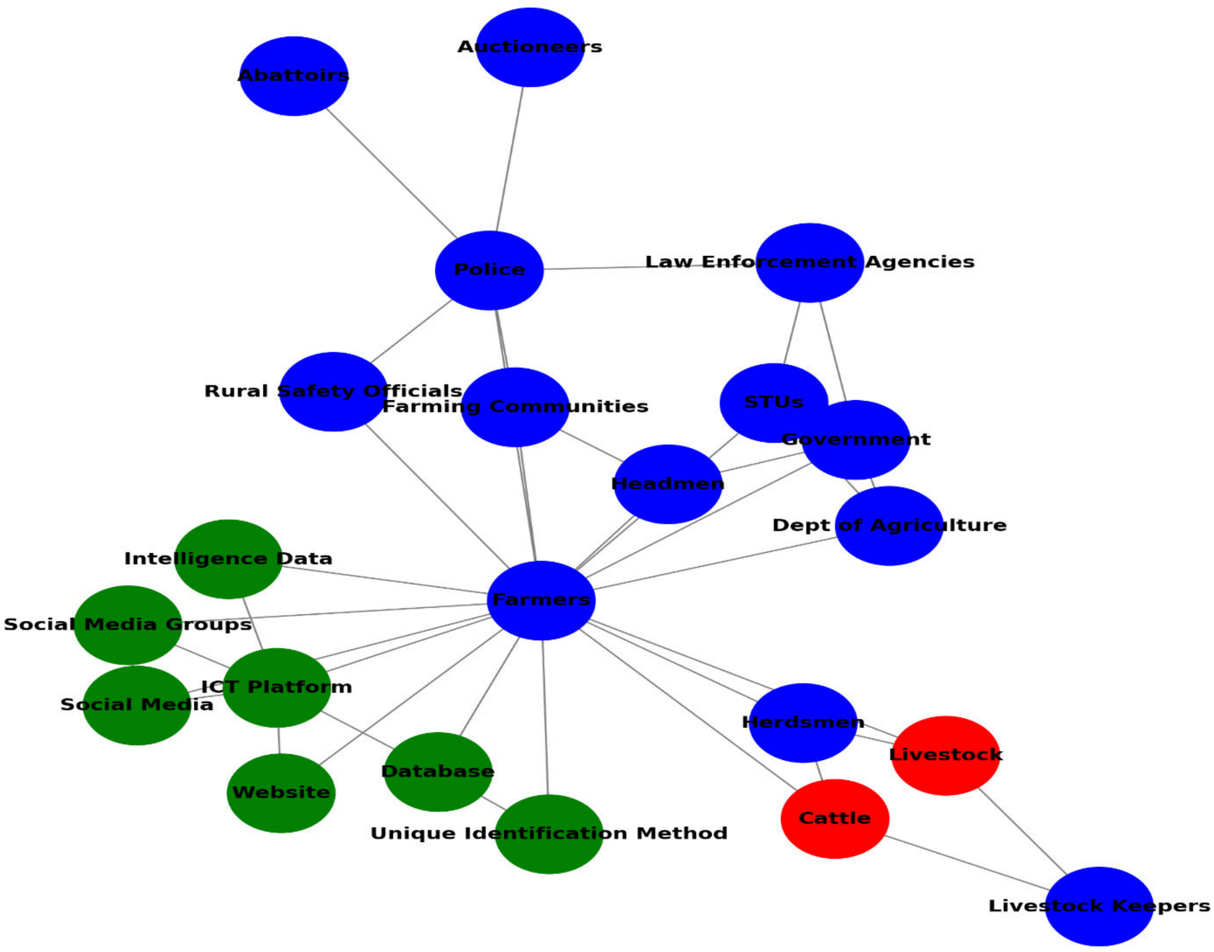


Figure 22: A sociogram based on the identified key human actors and non-human actors
Source: Researcher's analysis of primary and secondary data: Research Questions 2 and 3 respectively.

7.3.3. Research Question Four

This section addresses the research question numbered four as outlined in chapter one. It is important to explore the nature and extent of use of livestock identification methods and tracking methods by the human actors for controlling, mitigating, or combating livestock theft in South Africa. This sub-section is organized into two parts, namely: (i) Situation regarding livestock identification in South Africa**,** and (ii) Situation regarding tracking stolen livestock in South Africa.

7.3.3.1. Situation Regarding Livestock Identification Methods in South Africa

Research participants expressed their experiences, views, perceptions, insights and perspectives on situation about livestock identification methods in South Africa. The STU interviewees emphasized that all South African livestock farmers, by law, are required to brand their livestock with official identification marks (one to three characters issued by the Department of

Agriculture`s database). This is legally stipulated in the Animal Identification Act of 2002. However, members of the Stock Theft Unit were of the view that many livestock farmers do not comply with Animal Identification Act 2002. One member of the Stock Theft Unit indicates that "*We have encountered many incidences of lost, stray or stolen livestock which are not branded with official identification marks as per Animal Identification Act 2002. This makes it difficult to trace-back the livestock to the owner*". Another member of the Stock Theft Unit mentioned that *"rural farmers leave their livestock stray without official branding*". The members of Stock Theft Preventative Forum had similar views. For instance, one member points out that "*inappropriate branding of livestock among communal farmers is a big problem*."

Although in the literature there are reported electronic-based livestock identification methods used by farmers in the country (Weekly Magazine, 2015a; Lombard et al., 2017; Maluleke, 2018), the literature revealed that many livestock farmers in South Africa use their traditional identification methods to brand their livestock (Katikati & Fourie, 2019; Maluleke, 2018; Lombard et al., 2017; Lombard & van Niekerk, 2017; Clack & Schutte, 2015; Stock Theft Preventative Forum, 2015; Farmer`s Weekly Magazine, 2015a; Meissner et al., 2013). This concurs with the responses obtained from the livestock farmers, animal production specialists/professionals, headmen, members of the Stock Theft Preventative Forum, and members of the Stock Theft Unit. For instance, one member of the Stock Theft Preventative Forum stated that: "*Most rural livestock keepers in the Eastern Cape use ear tags, ear notches and hot iron branding to mark their livestock*". Similarly, the farmers interviewed confirmed that they use their own hot iron branding marks and ear notch marks when asked how they identify their livestock. Some farmers said that they can see their livestock through observation (colours and shape). One animal production specialists/professionals who had experience in working with livestock farmers indicates that: "*Farmers apply different methods to safeguard their livestock, including herding during the day, kraaling at night, iron branding, tags and notches*". In the literature there is a general consensus that conventional livestock identification methods are ineffective for controlling or mitigating livestock theft. These include ear tags (plastic and metal), collar tag /neck chains, ear notching, hot iron branding, freeze iron branding, tattooing, drawings and descriptions, paint branding. Hence, ICT-based livestock identification methods have been extensively recommended in the literature.

The forensic DNA technology is used by the SAPS in collaboration with Agricultural Research Council of South Africa to address the livestock theft challenges in South Africa. One animal production specialist/professional from the Agricultural Research Council of South Africa cited some strengths of forensic DNA technology in dealing with livestock theft in South Africa. For instance, he states that: "*The police have been able to link livestock crimes to the associated criminals. Forensic DNA analysis can be an important tool in the conviction of stock thieves. DNA technology provides a tool for animal identification and prosecution of livestock thieves. Nationally, animal forensic and dispute cases have been resolved through DNA typing and the results have been presented in South African courts*". Similarly, in the literature, the strength of forensic DNA technology was highlighted by Maluleke (2021), Hofmeyr (2018) and Zwane et al. (2013).

However, the production specialist/professional from the Agricultural Research Council of South Africa mentioned some constraints associated with forensic DNA technology. He states that: "*A huge challenge, however in animal forensics is the nature of samples submitted for DNA analysis. Samples are often aged or degraded, resulting in a compromised efficiency of using DNA profiling in forensics cases*". The forensic DNA technology, despite offering reliability in identifying livestock, has some drawbacks. The forensic DNA technology is a long and costly process because it requires a laboratory environment and at least several hours or days or weeks or even moths to identify livestock. These constraints were discussed in chapter five. The findings on constraints associated with forensic DNA technology are consistent with Maluleke (2021) and Zwane et al. (2013) when they pointed out its weaknesses for controlling livestock theft. Due its weaknesses, the forensic DNA technology is not suitable for routine livestock identification.

The members of Stock Theft Preventative Forum are of the view that few commercial livestock use electronic-based technology to identify and track their livestock. One member of Stock Theft Preventative Forum mentions the use of a GPS collar device. *"I know of commercial farmers in Northern Cape and Western Cape who are using a GPS system to monitor their sheep. The system helps the farmers in cases of theft. It can send alerts to livestock farmers*". This finding aligns with Booysen (2019), Maluleke (2018) and Cattle Watch (2017). Similarly, one Animal Production Specialist/Professional suggests a tracker-based device that can be used to monitor livestock: "*It would help if livestock could be fitted with a device that can be able to track their location*". Various GPS tracker-based system for controlling or mitigating livestock theft were proposed in the literature (Chikwuma & Francis, 2014; Scheepers et al., 2017; 2014; Clark, 2006).

The Animal Production Specialist/Professional was skeptical about the cost such tracker device: "*The devices would need to be of low tariff to be affordable for rural livestock holders*". Another Animal Production Specialist/Professional had 'reservations' about using technology on animals: "*For cultural/religious reasons, some communities may not want their animals to be* *chipped with technology. Some people believe in ancestors*". Zantsi & Nkunjana (2021), Maluleke (2018) and Maluleke (2017) obtained similar findings. Maluleke (2018) emphasised that the value of utilising GPS trackers among communal farmers is still unknown.

Despite the rapid development in GPS tracking devices (Digital Matter, 2022; Smarter Technologies, 2022), Maluleke (2018) and Maluleke (2017) pointed out some limitations and shortcomings of GPS tracking devices. One of the major shortcomings is the cost (purchasing, setup maintenance, etc) of GPS tracking collars. Another major shortcoming is power consumption and limited battery lifespan of GPS tracking collars. The lack of business cases of GPS tracking devices among communal farmers in South Africa is also a concern (Maluleke, 2018). These findings and implications suggest that financial barriers, operational challenges and community-specific considerations need to be carefully addressed when seeking to implement a sustainable livestock identification and tracking system in diverse agricultural settings like South Africa.

As already discussed in chapters three and five, livestock identification methods can be classified into: traditional methods, biometric methods, technological methods, community-based methods, legal methods, and advanced technological methods. According to Greenwood et al. (2014), chemical methods and behavioural methods can also be used to identify livestock. A summary of the findings on the situation about livestock identification methods in South Africa is illustrated in table 28 and figure 23.

Table 28: A classification of livestock identification methods and those commonly used by stakeholders in South Africa

Classification of livestock identification methods	**Commonly used in South Africa?**	**Stakeholders using it.**
Traditional methods	Yes.	Mostly farmers.
Biometric methods	No.	--------------
Genetic methods	Yes. DNA.	SAPS and ARC.
Technological methods	Yes. GPS trackers.	Some commercial farmers.
Community-based methods	Yes, especially shared grazing spaces.	Mostly communal farmers.
Legal methods.	Yes. AIS exist.	SAPS have access to AIS.
Advanced technological methods	No.	--------------
Chemical methods	No.	-------------
Behavioural methods	No.	--------------

Source: Author`s own illustration

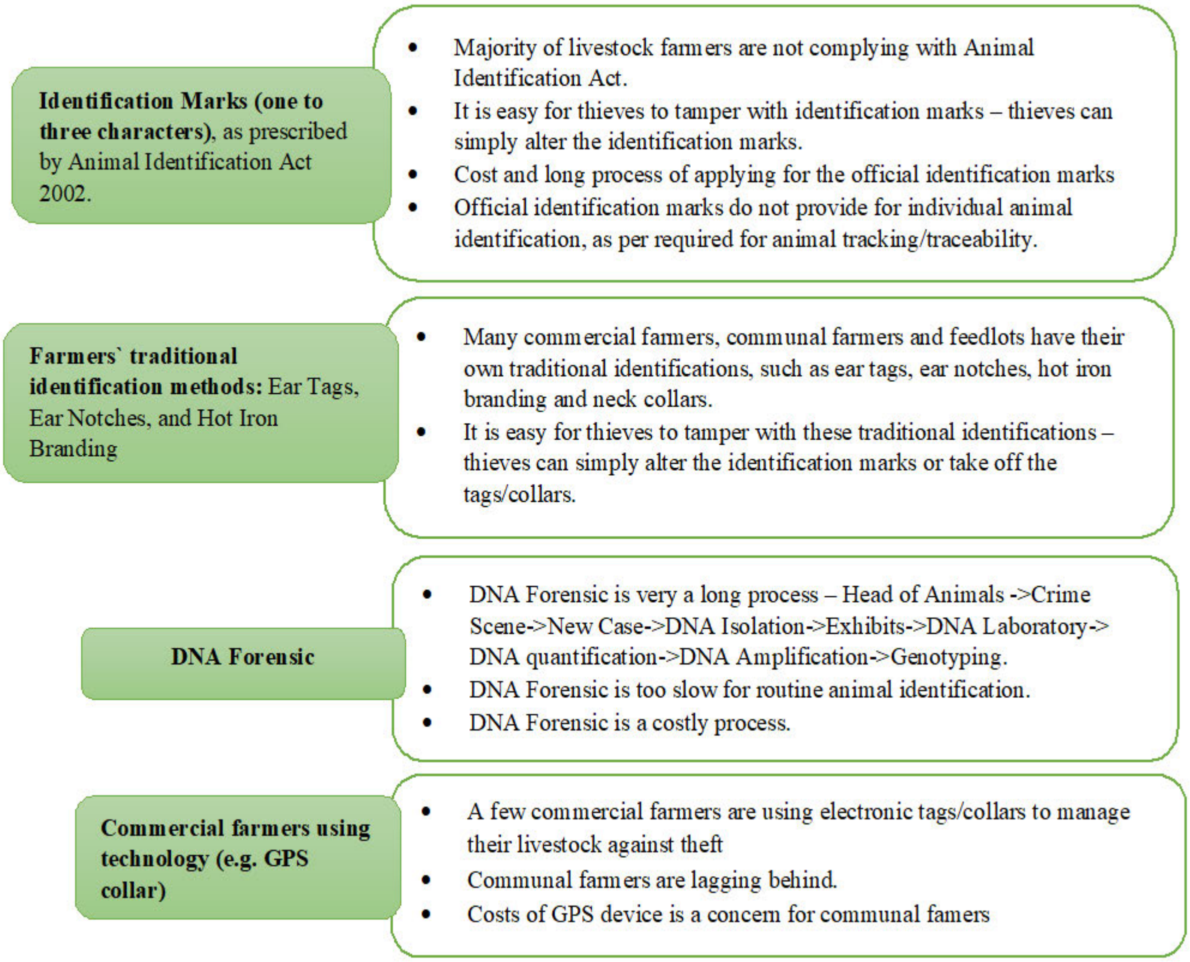


Figure 23: Situation regarding livestock identification methods in South Africa
Source: Author`s own illustration

7.3.3.2. Situation Regarding Livestock Tracking Methods in South Africa

Research participants expressed their experiences, views, perceptions, insights and perspectives on the situation about tracking methods in South Africa. The STU interviewees point out ‘stock raids by SAPS’, ‘looking for stolen livestock in the animal pounds’, and ‘road blocks by SAPS’ as their methods/strategies for tracking the stolen livestock. For instance, one member of Stock Theft Unit states that: “S*tock raids are conducted in suspected hotspot areas. All livestock in the suspected community are gathered in one place to search the stolen livestock. We use cars, horses and a group of Police. We go with livestock victims to the suspected community to search for stolen livestock*”. He further points out some challenges associated with stock raids by SAPS: *“Livestock holders do not brand their livestock with official identification marks. Sometimes SAPS does not succeed with finding the livestock through stock raids”*. Similarly, one member of Stock Theft Preventative Forum mentions some challenges experienced by the police community when tracking for stolen livestock: *“Tracking stolen livestock is a huge task, because thieves transport livestock using trucks and vans to distance locations. Theft of livestock is an organized business”*.

One interviewed livestock farmer has a similar view when he states that: "*Not much assistance is received from the police because in most cases neither stock is retrieved nor the culprit apprehended. Cases are reported to the police but more often than not, corrupt activities seem to crop in between the rule of law and culprit*". In addition to stock raids and road blocks, SAPS employs the joint operation approach when tracking stolen livestock as reported by Pasiwe et al. (2021). The joint operations are collaborations between SAPS`s Stock-theft Unit and Crime Intelligence. However, Pasiwe et al. (2021) found that the joint operations were not usually planned, they usually relied on tip-offs from informants. In the literature, there is a lack of research on 'stock raids by SAPS'. Further extensive research could help uncover the dynamics of 'stock raids by SAPS'.

The livestock farmers reveal that most farmers rely on random researching, community forums, the police, and farming communities as their methods/strategies for tracking stolen livestock. One communal farmer mentions that "*Since the livestock can be early identified the number on the ear and the colours, the victims go about searching from farm to farm and from dipping tank to another*". One communal farmer states that: "*The Masifunisane forum assists in searching for the missing livestock*". Another communal farmer indicates that: "*The herd boy has a duty of searching for livestock when it is missing"*. One farmer mentions a community forum: "*BARUAKGOMO forum, members phone one another. But it not easy to catch thieves, they use horses to steal livestock*". One communal farmer mentioned Imbizo (a gathering of the village community) as a strategy for searching for stolen livestock: "*Stolen livestock is also reported to headmen. The headmen calls for imbizo*". Other farmers mentioned 'Umbutho', 'Protection', and 'Isolomzi' as local forums for strategic searching of stolen livestock. These findings suggest that livestock farmers commonly rely on informal and community-based methods for tracking stolen livestock. The imbizo and community forums such as *Masifunisane forum, Umbutho, Protection, Isolomzi and BARUAKGOMO forum* might be another area of interest for further extensive research; because there is lack of research in the literature. Further extensive research could help uncover the dynamics, challenges and successes of these community-based methods for tracking stolen livestock.

The literature generally suggests that tracking stolen using conventional methods is ineffective towards controlling livestock theft. This suggestion is supported by the gathered empirical data, as stated by one commercial farmer stated that: "*Livestock victims report stock theft to the Police, the Police then using a docket assist in finding the stock and thieves. It is difficult to find culprits because stock theft is an organised crime by clever criminals".* The lack of trust of police among livestock farmers further exacerbates this challenge. Further extensive research in this regard could be useful to uncover the factors contributing to the lack of trust, and thus recommend suggestions for building trust between the two parties.

The involvement of many ‘players’ in the scourge of livestock-theft makes it difficult to track the stolen livestock. For instance, a member of Stock Theft Preventative Forum raised the issue of slaughter houses being involved in the ‘chain’ of livestock theft: “*to be honest I suspect that slaughter houses and ShisaNyamas are also involved in the syndicate*”. Similarly, one farmer raised the issue of law enforcement agencies being involved in the livestock-theft syndicate: “*Remember some Police also own stock, it might happen that some of them have a hand in stock theft*”. Another member of Stock Theft Preventative Forum raised the issue of farmers being involved in livestock-theft: “*You find some communal farmers with large sums of stock, and you wonder how they acquired such stock*”. This finding is another evidence of the sophisticated and organized nature of livestock theft in the country. This then implies that the challenges posed by the involvement of various players in livestock theft highlight the limitations of conventional livestock tracking methods. These challenges suggest for more technologically-driven tracking methods. In this regard, ICTs can a play crucial role in addressing the sophisticated and organized nature of livestock theft in the country. In contrast to the proposed ICT-based solutions that focused at farm level or community level, this study seeks to fill the gap by proposing a comprehensive ICT-based solution to control livestock theft in the country.

In chapter five, it was established that there is limited or lack of coordinated and national ICT use among livestock stakeholders in identifying and tracking lost/missing/stray/stolen livestock in South Africa. This information is consistent with responses from the research participants; for instance, one farmer stated that: “*Stock theft search is unlikely broadcast in the local radio station or social media*”. A member of Stock Theft Preventative Forums had a similar view when he stated that: “*There is a lack of radio programmes dedicated to livestock matters*”. Despite radio and TV being the common forms of ICTs in Africa, there is a lack of research on the role, use, potential and impact of radio and TV in addressing livestock theft. Further extensive research could help uncover the dynamics, challenges and successes of these traditional ICTs for addressing stolen livestock.

The potential of mobile phone technology in dealing with livestock theft was discussed in chapters three, four and five. The similar potential of mobile phone technology was expressed by the research participants. For instance, one farmer stated that they communicate with herd boys and agricultural officers through mobile phone technology; “*through the use of cell phones we* *communicate with the herd boy and agricultural officers to know the welfare of the livestock*". The police communicate with livestock victims via mobile phones, as revealed by a response from a member of Stock Theft Unit: "*once the victim has opened a case, an SMS is sent to his phone with a case number. We then do the follow up of the case. We phone the victim*". One headman mentioned the use of SMS when calling out an Imbizo: "*Phone messages are sent to the villagers informing them about the date and time of Imbizo*". One farmer mentioned the use of mobile phones when dealing with livestock-theft matters: "*as members of Masifunisane, we call one another and inform one another about stock theft in our community*". In the literature, there is extensive empirical evidence on the mobile network penetration in the country. The penetration includes 3G, 4G and G5 networks (ICASA, 2022). There is empirical evidence on the adoption of mobile phones, including smartphones in the country. The mobile network penetration and adoption of mobile phones present a promising avenue for controlling/addressing livestock theft in the country.

In the literature, various mobile phone based systems/solutions for mitigating livestock theft were proposed (Kriel, 2020; Sirotek & Hart, 2019; Lemma et al. (2019b); Katamba & Mutebi, 2017). These findings suggest a growing interest and exploration of mobile phone based solutions/systems in addressing the problem of livestock theft. The findings create a foundation for further research, development, and potentially practical implementation of phone based solutions/systems to control livestock theft.

From the gathered data, the researcher classified the common tracking methods used to track stolen livestock in South Africa into: law enforcement methods, community-based methods, ICT-based methods, traditional and informal methods. The categories are illustrated in table 29 below. This classification highlights the diverse range of methods employed to track and recover stolen livestock in South Africa. Each method has its strengths and challenges, indicating the need for a multifaceted approach to effectively address the issue. Further research is needed to explore the potential of various methods, particularly ICT-based solutions and community-based strategies, to improve livestock theft mitigation.

Table 29: A classification of livestock tracking methods commonly used by stakeholders in South Africa

Livestock Tracking Methods	Commonly used in South Africa?	Stakeholders using it.
Law enforcement methods.	Yes. Stock raids, road blocks road blocks, and joint operations.	SAPS.
Community-based Methods.	Yes. Masifunisane, Umbutho, Imbizo, Isolomzi, and BARUAKGOMO	Farmers.
ICT-based methods.	Yes. Mobile phone technology.	Farmers.
Traditional and informal methods.	Yes. Personal searches and herd boys.	Farmers.

Source: Author`s own illustration

Furthermore, figure 24 below highlights the findings obtained from the gathered data in relation to the situation regarding tracking stolen livestock in South Africa. The challenges of each method are also highlighted in this figure.

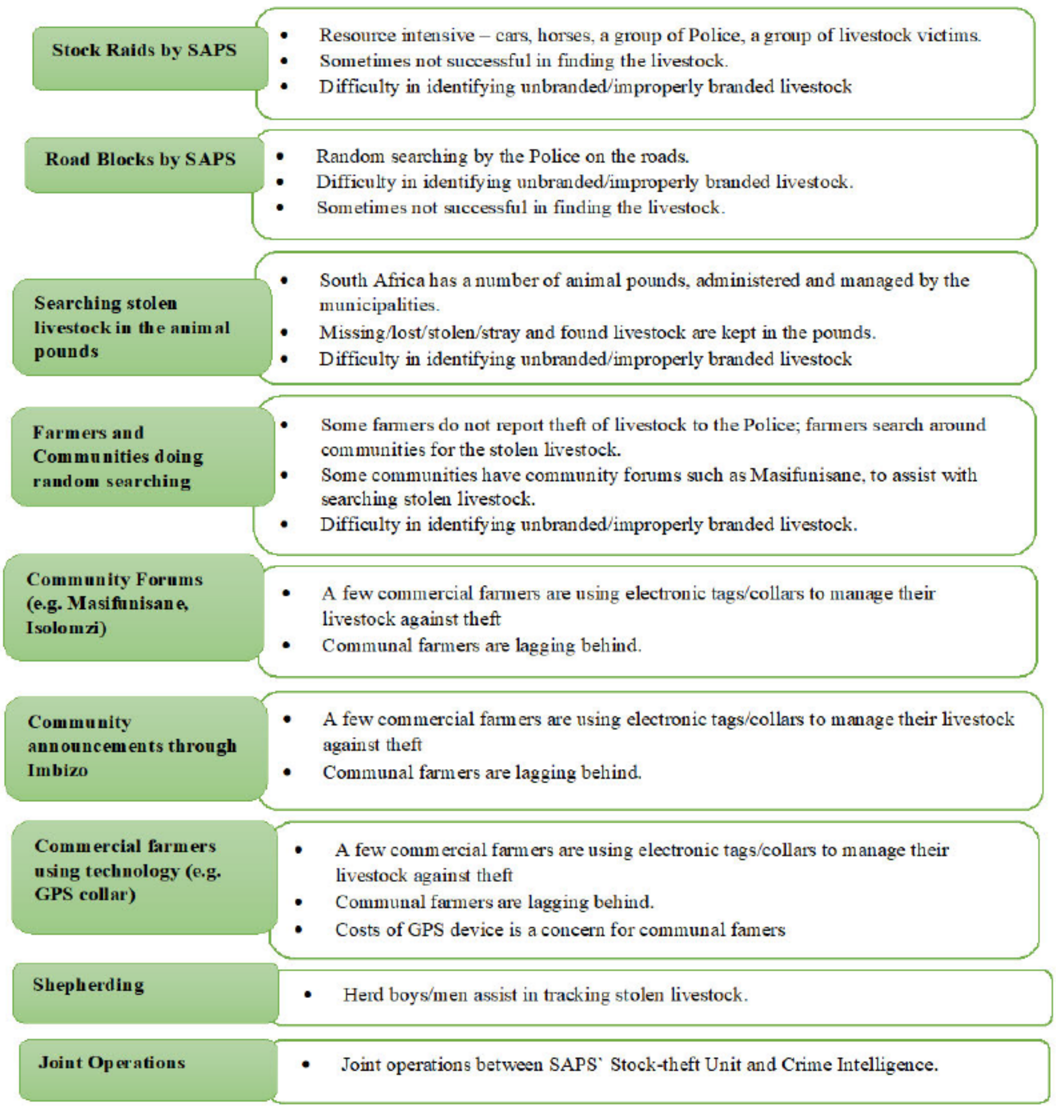


Figure 24: Situation regarding tracking stolen livestock in South Africa
Source: Author`s own illustration

7.3.4. Research Question Five

This section addresses the research question numbered five as outlined in chapter one. To explore how livestock stakeholders can use ICTs to control livestock theft in South Africa, it is important to identify the ICTs that has been adopted by livestock stakeholders. In this regard, from both an empirical data perspective and a secondary data perspective, the main purpose of this research question was to explore the important non-human actors (ICTs) to include in the livestock identification and tracking system for controlling livestock theft in the country.

In chapter two, it was established that mobile phone technology, radio, television, social media and instant messaging are some of the most adopted ICTs by the livestock farming communities in the country. The information on mobile phone technology is consistent with the responses obtained from the research participants. For instance, a member of STUs stated that "*The only technology we use in dealing with stock theft is phones when we want to call the victims*". Some farming communities use mobiles to mobilize community members for imbizo (gatherings) on matters related to livestock, as stated by one headmen: "*Phone messages are sent to the villagers informing them about the date and time of Imbizo*". Similarly, one farmer stated that: "*As members of Masifunisane, we call one another and inform one another about stock theft in our community*". These findings provide further evidence of mobile phone technologies as promising tools for controlling/addressing livestock theft in the country, as established in section 7.3.3.2.

In chapter three, it was established that surveillance cameras, collars with GPS tracker devices were some of the ICTs adopted by some selected commercial livestock farmers. The information on collars with GPS tracker devices is consistent with the responses from one member of Stock Theft Preventative Forum when he stated that: *"I know of commercial farmers in Northern Cape and Western Cape who are using a GPS system to monitor their sheep. The system helps the farmers in cases of theft. It can send alerts to livestock farmers*". It is worth noting that in the context of communal livestock farmers who are characterized by low levels of income, these ICTs are expensive; as supported by a member of Stock Theft Preventative Forum who stated that: "*The problem has to do with costs. GPS devices can be expensive. Can small farmers afford it? That is the problem*". It is also worth noting that any device attached to an animal can be removed by thieves before stealing the animal. The only electronic methods that offer some sort of permanence are microchipping and bolus. However, these two methods have drawbacks such as animal welfare issues, harming the animal, recycling burdens, and administrative burdens;

as discussed and evaluated in chapter four. These findings and implications provide further evidence of financial barriers, operational challenges and community-specific factors associated GPS tracking devices, as established in section 7.3.3.1.

7.3.5. Research Question Six

This section addresses the research question numbered six as outlined in chapter one. The main purpose of this research question was to explore the important, relevant and suitable actors (i.e. ICTs, livestock stakeholders, data, information, livestock identification methods, livestock tracking methods, etc.) to include in the livestock identification and tracking system for controlling livestock theft in the country.

During the initial stages of the research process, the researcher conducted a preliminary literature review. At this stage, the researcher found that globally there are many types of ICTs that are relevant for controlling/mitigating livestock theft. However, some types of ICTs may not be suitable for the South African context due to economic situation of livestock farmers, low ICT adoption/penetration rates, ICT infrastructure challenges, and socio-cultural factors in the country. In this regard, the research participants (ICT specialists) were asked to rank specific ICTs according to their 'importance', 'not important', 'less important' or 'not relevant' for the design and development of an information system that can identify and track livestock within the South African context. The questionnaire was used for this data collection exercise. The questionnaire was divided into several sections. The two sections (section 3 and 4) were about 'Hardware Technological Tools, 'Application Software and Communication Technologies', 'Wireless Technology Coverage', 'Livestock Identification and Tracking Technologies', and 'Emerging ICTs'. Furthermore, the questionnaire had an open-ended sub-section to allow ICT specialists to express their views, perceptions, insights, experiences and perspectives.

All the ICT specialists ranked radio, mobile phones, computers and surveillance system as 'important' for the design and development of an information system that can identify and track livestock within the South African context. Toll-free telephone number, SMS, online social media, automated telephone voice, mobile application, web application, desktop client application, and e-mail were ranked by the ICT specialists as 'important' for the design and development of an information system that can identify and track livestock within the South African context. Likewise, the wireless network coverage (3G, 4G, Wi-Fi hotspots, LITE, WinWax) were ranked by the ICT specialists as 'important' for the design and development of an information system that can identify and track livestock within the South African context. Only three ICT specialists ranked IoT technology as 'important' for the design and development of an information system that can identify and track livestock within the South African context. Regarding 'Livestock Identification and Tracking Technologies', RFID, GPS/LBS/RTLS, and image processing (biometric scanning) were ranked by the ICT specialists as 'important' for the design and development of an information system that can identify and track livestock within the South African context. With the exception of radio, surveillance system, toll-free telephone number, automated telephone voice, and e-mail, all other ICTs align with the broader literature. This gap in the literature opens avenues for further investigation into the relevance, role, effectiveness and potential associated with the excluded ICTs in the context of controlling or mitigating livestock theft.

As already stated above, the questionnaire had a section with the open-ended questions to allow research participants to express themselves. An example of data analysis process using sample quotes and content from the gathered data, emerged categories, and emerged themes as illustrated in table 32 below. For instance, one ICT specialist stated that "*Farming communities can group themselves to create common identities and markings of cattle in addition to individual identification to make their animals easily recognizable*". From this open-ended response, actors according to ANT were identified as 'farming communities, database, branding equipment, and cattle'; while the type/category of 'actor-network' formed by the actors for a common agenda would be a 'local cattle identification system'. For instance, one participant said that: "*Communities need to work hand-in-hand and report cases of livestock theft*". From this open ended response, actors according to ANT were identified as 'farming communities, and livestock'; while the type/category of 'actor-network' formed by the actors for a common agenda would be a 'collaborative livestock theft reporting system'. From the analysis of the selected open-ended responses, various types/categories of 'actor-network' that could be formed by the actors for common agendas emerged, as illustrated in table 32 below. The emerged types/categories of 'actor-network' include:

Low-cost livestock location tracking through tracker devices: This approach is based on the idea of using GPS tracker devices and GSM tracker devices to locate and track livestock anywhere on earth. This finding aligns with the broader literature because, various GPS tracker-based system for controlling or mitigating livestock theft were proposed in the literature (Chikwuma & Francis, 2014; Scheepers et al., 2017; 2014; Kim et al., 2010; Siror et al., 2009; Clark, 2006). In chapter four, it was established GPS tracker devices are expensive. The 'close' low-cost livestock location tracking approach is the Bluetooth-based system, as proposed by Maroto-Molina et al. (2019) in Spain.

Livestock monitoring through drones and mounted cameras: This finding aligns with the broader literature, because the importance and relevance of drones for controlling livestock were encountered in the literature (Maluleke, 2020; Du Pisanie 2018; Hodgson et al., 2018; Greenwood, 2016; Hoymer, 2015). Further to this, some drone-based systems were proposed in the literature (Vayssade et al., 2019; Soesilo and Rambaldi, 2018; Swain et al., 2018). Some examples of use of drones were discussed in chapter five. The capabilities, advantages and disadvantages of drones were discussed in chapter four. As discussed in chapter five, drones can be integrated with sensors and cloud computing to strengthen livestock identification, monitoring, tracking, counting, etc. However, in the literature, there is limited research on integrating drone technology with other technologies such as cloud computing, IoT, machine learning, AI and robots for livestock theft control/mitigation.

Local cattle identification system: This suggestion emerged from the research participants. It is based on the idea of establishing a livestock identification system for a particular farming society, rather than establishing a generic livestock identification system. The idea is based on taking into consideration the needs, socio-cultural issues and conditions of the particular farming society. This finding is consistent with Imtihan et al. (2021), Lemma et al. (2019b) Coll (2022), Katamba (2019), Molotsi and Makombe (2019), Sattarov et al. (2019), Chikwuma & Francis. (2014), Dieng et al. (2017) and Wamuyu (2017).

Alerts (notifications) through mobile devices: This approach is based on the idea of information exchange among the affected communities through SMS alerts, MMS alerts, instant messaging alerts or alerts through any relevant mobile app using mobile phones. In the literature, various systems with an ‘alert’ functionality/feature were proposed by various authors, as reported by Nunns et al. (2022), Ilyas & Ahmad (2020), Booysen (2019), Katamba (2019), Gbemisola et al. (2018), Chikwuma & Francis (2014), Lourie (2017), Maluleke (2017), and Tangorra et al. (2013).

Livestock population register though computerised database: This emerged idea is consistent with Odendaal (2020), Çelikyürek et al. (2019, and Molotsi and Makombe (2019), as established in chapter five. DALRRD (2021) estimated that South Africa`s livestock farming sector had a population of about 12-million cattle, 21-million sheep and 5-million goats in 2021. It would be difficult for a livestock identification and tracking system to store huge amounts of livestock data and livestock farmer’s data without a data repository (database). The creation, maintenance, retrieval and permanent storage of livestock data, livestock farmer’s data, and livestock identification and tracking data would require a reliable, robust and resilient data management repository – a Database Management System (DBMS).

Livestock verification system: This system suggested by the research participants is based on the idea of establishing an information system for use by all the stakeholders involved in livestock supply chain. The stakeholders include the police, relevant government departments, slaughterhouses, livestock buyers and sellers, auctioneers, farmers, etc. As already stated in the previous section, Kumar & Singh (2020) recommended animal biometric system for implementing a livestock verification system. As already stated in the previous section, the majority of research studies and journal articles on ICTs and livestock theft that were found in the literature mainly focused on farmers as the key stakeholders in dealing with livestock theft. The study fills this gap by considering various stakeholders involved in livestock supply chain.

Social media networks: This emerged idea concurs with Nunns et al. (2022), Bunei (2017), and Clack (2015), as established in chapter five.

Web-based intelligence system: This suggested system is based on the idea of Business Intelligence (BI) reporting. In this context, BI refers to the tools and applications used for data integration, data cleansing and consolidation, storage of integrated data, reporting, querying and analytics. The main aim of BI technology is to analyse data and present actionable information to the stakeholders via reports, scorecards, cubes, dashboards and visualization, so that they can use the information to gain knowledge and make informed decisions (IBM, 2022b). In South Africa there are no accurate reports on livestock farmers` demographics, livestock population, livestock movements, livestock stock theft trends and stray livestock trends at the sub-place level, district level, regional level, provincial level and national level. There are no accurate records on the reporting of livestock theft, because some farmers do not report theft of livestock to the police. A BI based system can facilitate the analysis of livestock theft data. This could also present actionable information to help stakeholders at sub-place level, district level, regional level, provincial level and national level make informed decisions. While big data and analytics, cloud computing and machine learning were encountered in the literature (Akhigbe et al., 2021; Garcia et al., 2020; Katamba, 2019; Clark, 2017), research specifically focused on BI systems to address livestock theft is lacking. This gap on BI technology represents an opportunity for further exploration and research on the role, use/adoption, impact, evaluation and development of BI systems for addressing livestock theft.

Collaborative livestock theft reporting system: This suggested system is based on idea of 'uniting' farming communities through ICTs for a common 'cause'. The common 'cause' is about reporting livestock theft, and thus controlling livestock theft. In this regard, no proposed system or solution of this nature was found in the literature. The only related use case found in the literature is that of Statistieke (VAS) Facebook page, as reported by Clack (2015).

Online community forums: This suggested approach is similar to the suggested collaborative livestock theft reporting system, whereby farming communities and other relevant stakeholder could 'unit' through ICTs for a common 'cause'.

Big data analytics through cloud computing: The importance and relevant of big data analytics through cloud computing for controlling livestock was found in the literature (Akhigbe et al., 2021; Garcia et al., 2020; Katamba, 2019; Clark, 2017). This was extensively discussed in chapter five. Associated technologies such as IoT and machine learning were also discussed, as established in section chapter five.

Connected livestock society through IoT: This finding aligns with the broader literature on the importance, role and relevant of IoT for controlling livestock theft (Farooq et al, 2022; Akhigbe et al., 2021; Maluleke; 2018). The technologies enabling IoT were discussed and evaluated in chapter five. In the literature, various IoT based system were proposed (Imtihan et al., 2021; Joshitha et al., 2021; Priyanka, 2019; Ojo et al., 2021; Gbemisola et al., 2018; Stojkoska et al., 2018; Saravanan & Saraniya, 2018; Abdullahi et al., 2019; Dieng et al., 2017; Wamuyu, 2017). The implications of IoT for the South African context were discussed in chapter five.

Radio broadcasting: This suggested approach by the research participants is based on the idea of broadcasting matters related to livestock theft through radio. Despite the widespread adoption of traditional ICTs such as TV and radio, there is a lack broadcasting programmes on matters of livestock theft in the country. No research studies or papers have proposed a practical solution or a model on how the problem of livestock could be addressed through radio.

A summary of the findings is illustrated in table 30 below.

Table 30: The ICT-based 'actor-networks' that can be formed for livestock identification and tracking in the South African context

Sample Quote/Content	Source of Quote/Content	Codes/Nodes	Categories	Theme
"A small tracker device can be attached to livestock to track their whereabouts. However, the devices would need to be of low tariff for communal farmers."	Questionnaire.	The need for low-cost technologies.	Network: Low-cost location tracking system through tracker devices.	Actor-Network: GPS tracker device, livestock, farmers.
"Farming communities can group themselves to create common identities and markings of cattle in addition to individual identification to make their animals easily recognizable".	Questionnaire.	Importance of community based initiatives.	Network: Local cattle identification system.	Actor-Network: Farming communities, database, cattle, branding equipment, branding marks.
Alerts on whereabouts of livestock movements can be sent to mobile phones via cellular network or Internet.	Questionnaire.	Mobile devices as important actors.	Network: Alerts (Notifications).	Actor-Network: Mobile phone, livestock, connectivity (GSM, Internet).
"Matatiele and Maluti are mountanous terraine regions; cameras mounted on top of the mountains to monitor livestock from a distance can be installed."	Secondary data.	Drones and surveillance cameras as important actors.	Network: Livestock Monitoring.	Actor-Network: surveillance cameras, livestock, farming communities.
"Mobile Phones can report via SMS to the farmer when something wrong on livestock happens."	Questionnaire.	Mobile devices as important actors.	Network: Alerts (Notifications).	Actor-Network: Mobile phone, SMS, farmers, livestock.
"Computers can be used to keep livestock records."	Secondary data.	Computers as important actors.	Network: Livestock population register.	Actor-Network: database, computers, records, data, livestock.
"Movement of livestock can be traced through IoT. "	Questionnaire.	The importance of IoT actors.	Network: Livestock Tracing	Actor-Network: livestock, IoT devices.
If Things are connected, the animals can identify with the kraal, the truck that transport them, the auction center where they are sold. Rules can be made to create alerts when things are not normal."	Questionnaire.	The importance of IoT actors.	Network: Connected livestock society through IoT	Actor-Network: livestock, IoT devices, animals, kraals, transportation, buyers, sellers, rules,
"Government may force people who slaughter cattle to provide details and the origins of the livestock to the Police, that would help Police notice livestock that are reported missing or stolen".	Questionnaire.	The needs for an alliance of diverse human actors.	Network: Livestock verification system.	Actor-Network: Government, slaughterhouses, Police, livestock.

Sample Quote/Content	Source of Quote/Content	Codes/Nodes	Categories	Theme
“Communities need to work hand-in-hand and report cases of livestock theft”	Questionnaire.	Community alliances are important.	Network: Collaborative livestock theft reporting system	Actor-Network: Farming communities, livestock.
“Farmers should be empowered and encouraged to register with social media technologies. One example in Kenya is tweeting chief who has been able to combat crimes including stock theft. We should also think of creating a website to enable all law enforcement agencies to contribute intelligence data. These simple messages that are instantly uploaded to many”.	Secondary data.	The important of social networking.	Network: Social media networks, web based Intelligence System.	Actor-Network: Farmers, registration, social media, website, enforcement agencies, intelligence data.
“People at the same time can raise alert to people of stock theft that has occurred. This social media groups should also incorporate slaughterhouse personnel, police, local administrators etc.”	Secondary data.	The important of social networking.	Network: Social media networks	Actor-Network: Police, slaughterhouses, traditional authorities, social media groups,
“Groups can be formed where images or features missing stock can be posted. Members can help locate missing stock. Community members can advise one another regarding the whereabouts of one another’s stock. Buyers can post what they bought and see if there are no problems with the ownership of animals.”	Questionnaire.	The importance of forums.	Network: Alerts (Notifications) Network: Online Community Forums.	Actor-Network: livestock images, livestock features, livestock, farming communities, buyers, sellers, livestock owners.
South Africa has public radio stations and community/private radio stations. Information on livestock theft maters can be conveyed through radio.”	Secondary data.	Traditional ICTs as actors.	Network: Radio broadcasting.	Actor-Network: Radio stations, livestock, information.
“Queries about livestock can be done promptly. With large datasets with dispersed locations, location of animals can be more real-time.”	Questionnaire.	Modern and advanced ICTs.	Network: Big data analytics through cloud computing.	Actor-Network: Datasets, Internet, animals, cloud servers, machine-learning algorithms.

Sample Quote/Content	Source of Quote/Content	Codes/Nodes	Categories	Theme
"Mobile Apps may be used to track down locations of animals on real time basis. They can help farmers to take action when animals start grazing too far or on unfamiliar places. They can also be used to notify/verify with the registered owner during sales and auctions. They may be used to capture and update latest physical characteristics of an animal."	Questionnaire.	Modern and mobile based ICTs.	Network: Livestock register. Network: Notifications (alerts). Network: Location tracking. Network: Verification system.	Actor-Network: mobile devices, mobile apps, livestock, farmers, buyers, sellers, auctioneers.
The technology would maximize the availability of the data and efficiency by distributing data locations strategically. Regional data querying would be smoother and growth in data size would be better accommodated as animals breed."	Questionnaire.	Modern and advanced ICTs.	Network: Big data analytics through cloud computing.	Actor-Network: data, Internet, animals, cloud servers, machine learning algorithms.

Source: Researcher's analysis of primary and secondary data: Research Question 6

7.3.6. Research Question Seven

This section uses the primary data gathered through interviews and questionnaires and data gathered from secondary sources to address and answer the research question numbered seven as outlined in chapter one. This seeks to explore the attitudes, insights, perceptions and perspectives of research participants towards the use of ICTs in dealing with livestock theft in South Africa. Thus, from both an empirical data perspective and a secondary data perspective, the main purpose of this research question and objective was to explore the important, relevant and suitable ICTs to include in the livestock identification and tracking system for controlling livestock theft in the country.

The researcher explored the 'Sentiment' feature of NVivo to gauge the researcher`s participants attitude towards the use of ICTs in dealing with livestock theft in South Africa. Sentiment analysis refers to the process of analyzing digital text to determine if the tone of the text is positive, negative, or neutral (Amazon, 2024). The texts that contained words like concern, high-costs, risks, and challenge were associated with negative sentiment; while words like low-cost were associated with positive sentiment. Figure 25 below shows a sample of researcher`s sentiment analysis in NVivo software.

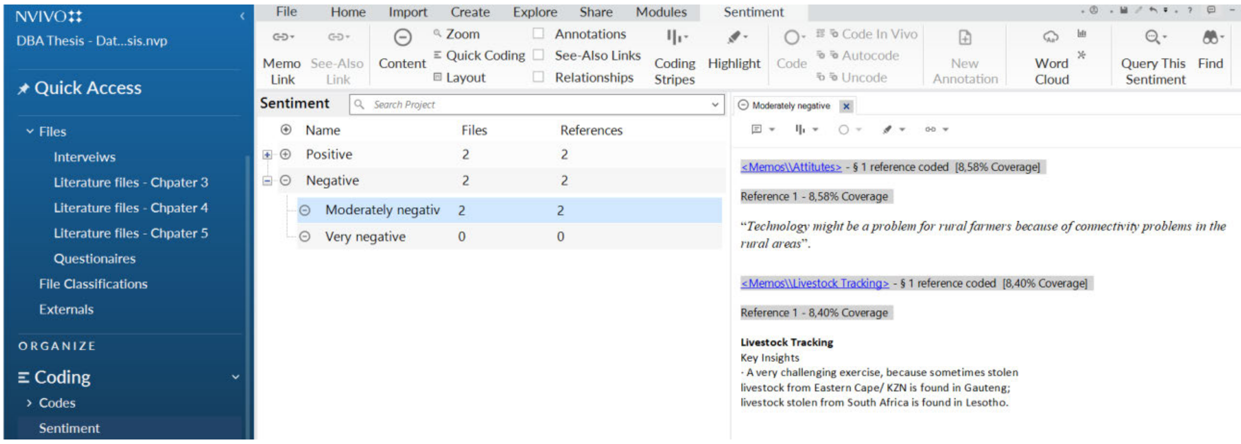


Figure 25: A screenshot of sentiment analysis in NVivo software
Source: Researcher's analysis of data using NVivo: Research Question 7

The Animal Production Specialists/Professions, and members of Stock Theft Preventative Forum raised a number of concerns with regards to using technology in managing livestock theft, as summarised and illustrated in figure 26 below. A member of Stock Theft Preventative Forum mentioned Botswana as example where implanting a bolus chip on livestock experienced problems: "*Technology is not always a solution. Look at Botswana. The bolus had technical problems there*". Another member of Stock Theft Preventative Forum was concerned about the cost of electronic devices used for tracking livestock, he said: "*The problem has to do with costs. GPS devices can be expensive. Can small farmers afford it? That is the problem*". One Animal Production Specialists/Professions had a similar view about the costs of tracker devices when he stated that: "*Maybe a tracker device can help reduce stock theft. The device would need to be of low tariff*". One Animal Production Specialist/Professional had 'reservations' about using technology on animals, he stated that: "*for cultural/religious reasons, some communities may not want their animals to be chipped with technology. Some people believe in ancestors*". All this information is consistent with information obtained from the secondary data sources and literature. For instance, in chapter four it was established that cost of GPS/RFID devices, risks of meat contamination, animal welfare issues were among the concerns with regards to livestock identification and tracking.

Connectivity in the rural areas was also a concern among the research participants. For instance, one animal production specialist stated that "*Technology might be a problem for rural farmers because of connectivity problems in the rural areas*". One ICT specialist had similar view, when she stated that "*Internet access may be a barrier in the rural areas*". This information is consistent with ICT developments and trends in the country that were discussed in chapter four. It was established that one of factors contributing to the slow ICT developments in the livestock farming sector is the lack Wi-Fi and Internet base stations in the rural areas. The adoption of smartphone has contributed to a growth in Internet access among rural based farmers, but mobile data is still expensive in the country.

Despite the negative perceptions on the use of technology on livestock expressed by the research participants, some expressed positive perceptions, as illustrated in figure 26 below. For instance, a member of Stock Theft Unit suggested the monitoring of livestock through the use of surveillance cameras, when he said that: "*Maluti region around Lesotho is a mountains terrain. Maybe some form of monitoring camera system can be installed on the top of the mountains to monitor the livestock*". One ICT specialist recommended mobile phone technology for tracking livestock: "*Mobile apps may be used to track down locations of animals on real time basis and help the farmer to take action when animals start grazing too far or on unfamiliar places".* Similarly, another ICT specialist added that: "*Smart farming communities may be a solution. Mobile phones can alert famers of the missing livestock*". One farmer suggested the use of radio and social media, when he said that "*Stock theft is rarely broadcast on radio and social media*".

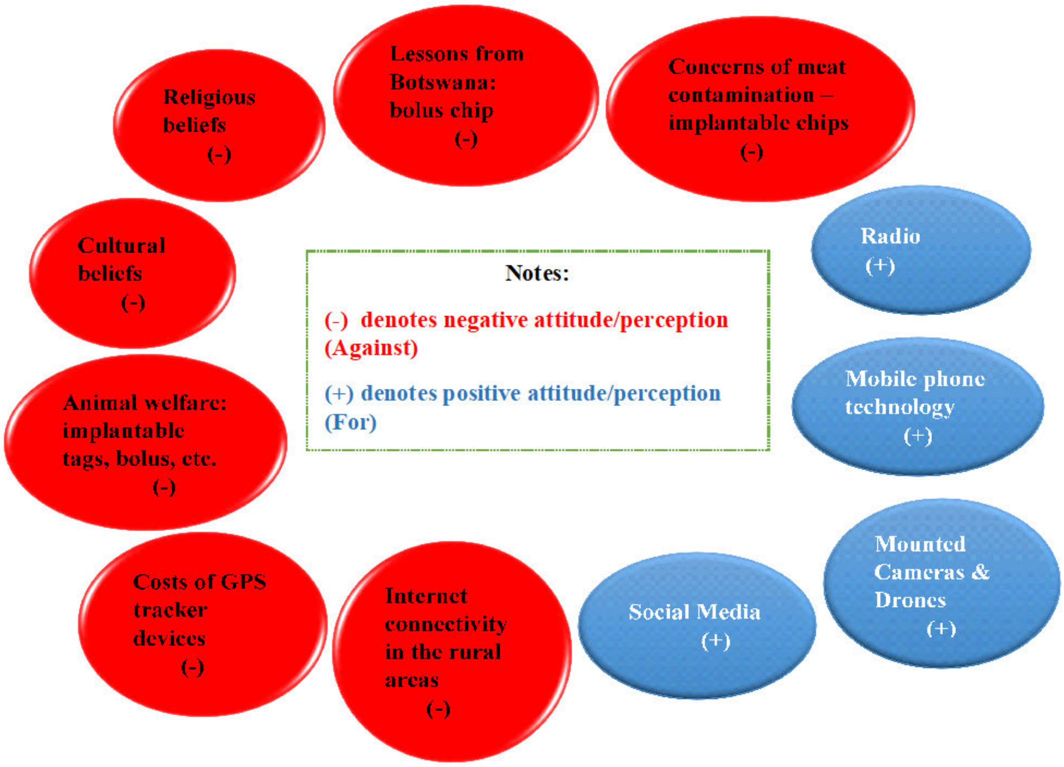


Figure 26: The attitude and perceptions of research participants towards the use of ICT in dealing with livestock theft in South Africa.
Source: The researcher’s data analysis

7.3.7. Research Question Eight

In chapter one, research question eight was posed as follows: “what are the information systems components required to develop a holistic/comprehensive and national livestock identification and tracking system for controlling livestock theft in South Africa?”. In chapter five, it was stated that this research study is conducted from an Information Systems perspective. The proposed model of a livestock identification and tracking system is an information system. By definition an information system is composed of a variety of elements including ICTs, data, people, procedures, methods, etc. This research question sought to establish the information systems components required to develop a holistic/comprehensive and national livestock identification and tracking system for controlling livestock theft in South Africa. By design, research question eight is a consolidation of research questions one, two, three, four, five, six and seven respectively. Through the consolidation of these seven research questions and the synthesis of information obtained from the literature and secondary data sources, the following information systems components have emerged:

- **National laws and regulations:** South African has established various laws and regulations pertaining to livestock in general, and livestock theft in particular. These laws were described in chapter four. Also, the country has policies governing ICT use; for example, drone use, as discussed in chapter five. Furthermore, South Africa's data protection law known as Protection of Personal Information Act (POPI Act) has been established. A holistic/comprehensive and national livestock identification and tracking system for controlling livestock theft in South Africa should be within the confines the laws and regulations of the county. Therefore, national laws and regulations can be considered as external components of an information system.

- **International and national standards:** In chapter five, it was established that WOAH (2022) and FAO (2017) recommend that a livestock identification and registration should be developed in accordance with international standards that are based on the most recent scientific and technical information. Therefore, international and national standards can be considered as external components of an information system.
- **Animal welfare**: In this chapter, one of the concerns raised by the research participants was animal welfare**.** In chapter five, it was established that when developing a livestock identification and tracking system, animal welfare needs to be taken into consideration, as recommended by WOAH (2022) and FAO (2017). Therefore, animal welfare can be considered as an external component of an information system.
- **People (various stakeholders from diverse structures):** In sections 7.3.2, 7.3.4, 7.3.5 and 7.3.6 respectively of this chapter, it has been established that there are various actors that need to be considered when developing a livestock identification and tracking system. In chapter four, the key stakeholders involved in the fight against livestock theft in the country were described. Their key interests were also discussed. Therefore, various stakeholders from diverse structures can be viewed as part of an information system.
- **Livestock:** In almost all the themes that emerged from the analysis of empirical data, livestock (for example, cattle) were identified as part of the various 'actor-networks'. For this purpose, livestock can be viewed as part of an information system.
- **Data:** Data is the cornerstone of any information system. Data pertaining to farmer details, and livestock unique identifications is important for a livestock identification and tracking system, as established in this chapter and chapters two, three, four, five.
- **Livestock identification methods:** In chapter four, three categories of livestock identification methods were discussed and evaluated: traditional/conventional livestock identification, electronic livestock identification methods, and biometric livestock identification methods. A livestock identification method is part of an information system.

- **Network connectivity:** Mobile phones were identified as one of the key actors required for a livestock identification and tracking system. Mobile phones rely on GSM networks to transmit information. In chapter five, it was established that GSM networks are important in the context of rural areas and livestock farming sectors. It is for these reasons that network connectivity can be considered as one of the important components of an information system.
- **Tracking technologies:** In this chapter, various tracking technologies were suggested by the research participants, including tracking using GPS devices, mobile phones, drones, and mounted cameras. Various tracking technologies/systems were discussed and evaluated in chapter five. Their implications to the South African context were discussed in chapter five.
- **Backend technologies and data repository:** Database, computers, and cloud infrastructure emerged as some of the important actors in this chapter. These ICTs enable the storage, retrieval, analysis and manipulation of big data. These ICTs can be considered as important components of an information system.
- **Reporting system functionality/feature - reporting of livestock theft:** In this chapter, **'**communities working together to report livestock' was a common expression that came out from the research participants. It is for this purpose that the livestock theft reporting functionality/feature can be considered as an important component of an information system.
- **End-user devices and applications:** Mobile phones, SMS, mobile apps, website, social media platforms are some examples of the identified components of an information system in sections 7.3.2, 7.3.4, 7.3.5 and 7.3.6 respectively of this chapter.
- **Business intelligence functionality/feature:** The research participants in section 7.35 of this chapter expressed the idea of queries about livestock, regional data querying, and large datasets. It is for this purpose that a business intelligence functionality/feature can be considered as part of an information system.

7.4. Summary of the Key Findings

This chapter has provided data analysis, interpretation of findings, and discussions of the gathered primary (empirical) data from the research participants. Secondary data and literature information were also used to support the data analysis, findings, interpretation and discussions in this chapter. The chapter has established that livestock theft is characterized by various coordinated and organized networks of national and international syndicates. The nature of the phenomenon has become commercial, involving diverse supply chain actors. The chapter has established that ear notches, brand marks and ear tags are the most common traditional/conventional methods that have been adopted by livestock farmers in the country. In chapter four, it was established that traditional/conventional methods are ineffective in dealing with livestock. Tracking of stolen livestock is largely conducted through resource intensive and labour intensive methods. The use of ICTs for tracking stolen livestock is not common. Several key actors (stakeholders, structures and institutions), their interests, relations and interactions were identified. However, there is a lack of coordinated and holistic national approach among the identified key actors to control livestock theft in the country.

Research participants expressed positive attitudes towards some ICTs such as radio, mobile phone technology, mounted cameras, drones, and social media. In chapter five, it was established that mobile phones, radio, social media and instant messaging are some of commonly adopted forms of ICTs in the country. Research participants expressed negative attitudes towards microchipping technologies because of cultural reasons, welfare issues, high costs, and religious reasons. From the gathered data, various types/categories of 'actor-network' that could be formed by the actors to control livestock theft in the country emerged. These include low-cost livestock location tracking through tracker devices, livestock monitoring through drones and mounted cameras, local cattle identification system, alerts (notifications) through mobile devices, livestock population register through computerised database, and livestock verification system, just to name a few.

The chapter has revealed that national laws and regulations, international and national standards, and animal welfare need to be considered when designing and developing an information system for controlling livestock theft. The information systems components required to develop a holistic/comprehensive and national livestock identification and tracking system for controlling livestock theft in South Africa have been determined in this chapter.

In the next chapter, the researcher employs the Design Science Research Methodology (DSRM) to develop a model of livestock identification and system for controlling livestock theft in South Africa. To develop the model, the key findings, insights, highlights and implications are drawn from chapters three, four, five and seven.

CHAPTER 8

THE PROPOSED MODEL FOR LIVESTOCK IDENTIFICATION AND TRACKING IN SOUTH AFRICA

8.1. Introduction

This chapter focuses on the study`s goal – the development of a model of an ICT-based livestock identification and tracking system for controlling livestock theft in South Africa. To develop an ICT-based and practical based solution, the key findings, insights, highlights and implications will be drawn from chapters three, four, five and seven. To fulfil the goal of the research study, a Design Science Research Methodology (DSRM) was adopted as the framework to present the conceptual model of a livestock identification and tracking system for controlling livestock theft in South Africa.

This chapter is organised as follows: The chapter begins with a brief description of DSRM and the justification for the use of DSRM. This is followed by an explanation on how the researcher used DSRM to create the model. The next section focuses on application of DSRM principles to create the model, in which the researcher 'follows' the DSRM principles to create the model. The last section concludes the chapter.

8.2. Design Science Research Methodology: Towards the Solution

The origins of DSRM can be traced back to both the Engineering and Computer Science disciplines, respectively (Oates et al., 2022; Wieringa, 2014; Peffers et al., 2007;). In chapter five, the researcher explained that this research study is conducted from an Information Systems perspective. In the previous years, DSRM has been adopted by several scholars in the IS research domain, including Cole et al., (2005), Hevner et al. (2008), (2004), Peffers et al. (2007), and Adams & Courtney (2004). The scholars in IS research domain successfully made the case of the validity and value of DSRM, including integrating design as a major component of their research (Peffers et al., 2007). In the context of DSRM, design refers to the act of creating an explicitly applicable solution to a problem (Kuechler & Vaishnavi, 2008; Peffers et al., 2007). This definition is in line with Hevner et al., (2008) who define DSRM as the methodology that can be adopted to address a problem through the process of creating an artefact (system, product, service, solution, model, etc). According to Peffers et al. (2007) and Oates et al. (2022), DSRM is a methodology based on the development of an applicable ICT artefact in context. The artefacts include models, methods, architectures, constructs, or a working system. Similarly, Wieringa

(2014) and Kuechler & Vaishnavi (2008) describe the artefacts that manifest from DSRM as constructs, models, frameworks, architectures, design principles, methods, instantiations, and design theories, as provided in table 31 below. The artefacts are intended to solve/address identified societal or organizational problems (Peffers et al., 2007).

Table 31: Outputs of Design Science Research Methodology

Output	**Description**
Constructs	The conceptual vocabulary of a domain.
Models	Sets of propositions or statements expressing relations between constructs.
Frameworks	Real or conceptual guides to serve as support or guide.
Architectures	High level structures of a system.
Design Principles	Core principles and concepts to guide the design.
Methods	Set of steps used to perform tasks – how to knowledge.
Instantiations	Situated implementations in certain environment that do nor do not operationalize constructs, models, methods, and other abstract artefacts.
Design Theories	A prescriptive set of statements on how to do something to achieve a certain objective. A theory usually includes other abstract artefacts such as constructs, models, frameworks, architectures, design principles, and methods.

Source: Kuechler & Vaishnavi (2008)

All the above identified definitions of DSRM are in line with the goal of this research study. The goal of the research study is to create an ICT-based model of a livestock identification and tracking system for controlling livestock theft in the country.

Some of the artefacts that will be embedded into the model are livestock identification methods and technologies, tracking methods and technologies, and system architecture diagrams. In this regard, the contribution of this chapter can be viewed as 'four-fold', namely: model, methods, technologies, and architectures; as described in table 33 above. Another justification for the adoption of DSRM in this research study has to do with the qualitative approach, interpretivism research paradigm, and type of research (applied research) discussed in chapter six. These three elements of research methodology (qualitative approach, interpretivism research paradigm, and applied research) 'work hand in hand' with DSRM (Kuechler & Vaishnavi, 2008).

Any research adopting DSRM is guided by DSRM activities, also referred to as DSRM process elements or DSRM principles. A number of scholars in the IS research community, Engineering research community and Computer Science research community came up with a common DSRM framework. The framework constitutes six DSRM activities as guiding principles for DS research in IS. The six activities are (i) Problem Identification and Motivation; (ii)

Objectives for a Solution; (iii) Design & Development of the Artefact; (iv) Demonstration; (v) Evaluation; and (vi) Communication (Peffers et al., 2007; Oates et al., 2022; Hevner et al., 2008). Table 32 below provides a brief description of each DSRM activity. In this chapter, the researcher will approach the development of a livestock identification and tracking system for controlling livestock theft in South Africa using the six DSRM activities identified by Peffers et al. (2007). In the context of DSRM, the model of a livestock identification and tracking system for controlling livestock theft in South Africa will be referred to as an artefact.

Table 32: Design Science Research Methodology (DSRM) activities

DSRM Activities	Activity Description	Knowledge Base
1. Problem Identification and Motivation	What is the problem? Define the research problem and justify the value of a solution.	Understanding of problem relevance and its current solutions and their weaknesses.
2. Define the Objectives of a Solution	How should the problem be solved/addressed?	Knowledge of what is possible and feasible. Knowledge of methods, technologies, and theories that can help with defining the objectives.
3. Design and Development	Create an artefact that solves/addresses the problem. Such artefacts are constructs, models, methods or instantiations in which a research contribution is embedded.	Application of methods, technologies, and theories to create an artefact that solves/addresses the problem.
4. Demonstration	Demonstrate the use of the artefact.	Knowledge of how to use the artefact to solve the problem.
5. Evaluation	How well does the artefact work?	Knowledge of relevant metrics and evaluation techniques.
6. Communication	Communicate the problem, its solution, and the utility, novelty, and effectiveness of the solution to the researchers and relevant audiences.	Knowledge of the disciplinary culture.

Oates et al. (2022); Peffers et al. (2007)

8.3. Problem Identification and Motivation

When adopting DSRM in a research study, the first step in the design process outlines the identification of the problem and its motivation (Peffers et al., 2007). As already stated in chapter one, the identified problem is about the scourge of livestock theft in South Africa, and cross-border livestock theft from South Africa into neighbouring countries. Furthermore, the conventional livestock identification methods and reliance on traditional/conventional methods of tracking stolen livestock are ineffective and inefficient in controlling livestock in the country. The objective is to address this issue through the development of an ICT-based artefact – i.e. the model of a livestock identification and tracking system for controlling livestock theft in South Africa. Despite calls for research on the topic of livestock theft and ICTs, this type of ICT-based artefact does not currently exist in the literature. The proposed model can serve as a “blue-print” for the implementation of a national and comprehensive livestock identification and tracking system for controlling livestock theft in South Africa.

8.4. Objectives for a Solution

The second step in the design process responds to the question of "how should the problem be solved/addressed?". This process requires the knowledge of what is possible and feasible, as well as methods, technologies, and theories that can help with defining the objectives of a solution (Peffers et al., 2007). In this step, the researcher will identify the key design factors and principles that guide the development of the artefact.

System Design Factors and Principles

System design factors refer to limiting factors that are considered when deciding on a way forward. Some examples of system design factors include suitability, reusability, scalability, accessibility, and standardization. Additional factors to consider are modularization, functional packaging, interchangeability, compatibility, fault isolation, identification, and low-cost (ISO, 2012). In the context of an ICT-based livestock identification and tracking system for controlling livestock theft, this section outlines the system design factors applicable to the South African context. From the primary data and secondary data gathered, the researcher has put forward the following system design goals illustrated in table 33 below.

Table 33: System design factors and principles for the proposed model

System Design Factors and Principles	Source/Reference	Justification
Permanent, tamper-proof, universal, unique, time-immutable, collectable and measurable identification method.	Chapters 3, 4, 5 and 7.	Given the nature, magnitude, and dynamics of livestock theft in the country, the conventional identification methods such as ear notches, brand marks and ear tags are ineffective in controlling livestock theft. Electronic methods such as RFID tags and GPS collar trackers can be easily removed by thieves, which means there would be no value derived from these electronic devices. Microchipping animals and boluses raise many concerns such as animal welfare, high costs, cultural issues and religious issues. In this case, the most viable identification would be a biometric method due to its permanence. It is tamper-proof, universal, unique, time-immutable, collectable and there is measurable capability.
Low-cost.	Chapter 3. Pienaar & Traub (2015.	Communal farmers are the majority in the country and they are characterised by low level of incomes. For instance, the average monthly income of a communal livestock farmer in a rural area of the Eastern Cape province is estimated to be R2732 per month (Pienaar & Traub, 2015). It is therefore, argued that access to the system should not cost the communal farmer more than his/her monthly income.
Less technical requirements from livestock farmers.	StatsSA (2018) Pienaar & Traub (2015.	More than 60% farmers in South Africa completed between grades 1 and 11 StatsSA (2018). It is important to meet the current literacy levels of the livestock farmers in the country. Pienaar & Traub (2015) in their study on communal farmers in South Africa found that the average age of the household head is 56 years, with an average of only 5 years of education; the equivalent of grade 5.
Adopted technologies by the livestock stakeholders in South Africa.	Chapters 3, 4, 5, and 7.	It was found the mobile phones were the most commonly adopted ICTs.
Availability and accessibility of technologies in South Africa.	Chapters 3, 4, 5 and 7.	For example, in chapter 5, drone availability and accessibility in South Africa was discussed.
Existing network infrastructure and coverage in South Africa.	Chapters 3, 4, 5 and 7.	Registration of animal identification into a database and verification of animal data requires a network to transport the data, and a receiving station to store and process the data. Tracking an animal involves a network. The GSM network coverage and GPS coverage are relevant in this regard.
Animal welfare.	Chapters 5 and 7.	The researcher found animal welfare is one of the requirements that need to be considered when developing a livestock identification and tracking system.
Standards.	Chapter 5.	The researcher found that standards are important when developing a livestock identification and tracking system.

Scalable.	Chapter 5.	When a new farming community wants to be included in the system, the system should allow simple scalability. This design factor can be achieved through a multi-tier architecture and cloud infrastructure, as discussed in chapter 5.
Modularization.	Chapter 5.	A typical livestock identification information system is made of up of several technical components. Such an information system is partitioned into smaller, independent, self-contained and manageable components.
Integration.	Chapter 5.	The smaller, independent, self-contained and manageable components are then integrated into a system.
Rural context.	Chapters 3 and 5 StatsSA (2018).	There are no Internet based stations or Wi-Fi in the rural areas. The digital divide between urban and rural in terms of access to the Internet and computers is common in South Africa. These factors need to be considered when developing a livestock identification and tracking system.

Source: Author`s illustration based upon contents of earlier chapters.

8.5. Design, Development and Demonstration of the Artefact

The design and development activity of DSRM is about creating an artefact. The artefact can be constructs, models, methods, instantiations, systems, or any objects that solve/address the problem, in which a research contribution is embedded. The activity requires an application of methods, technologies, and theories to create an artefact that addresses the problem presented (Peffers, 2007). In this section, the researcher creates an artefact in the form a model. The model is a livestock identification and tracking system for controlling livestock theft in South Africa. The researcher`s approach for developing the artefact is based on modular design methodology. This methodology partitions a system into smaller, independent, self-contained and manageable components. These components are then put together to create the fully envisaged and implementable "working" model of a system. The manageable components consist of creating and describing system architecture diagrams such as modules, block diagrams, context diagrams, and an Entity Relationship Diagram (ERD).

The artefact is divided into three major modules: (i) livestock identification and registration, (ii) livestock tracking, and (iii) knowledge management and dissemination on livestock theft. The first sub-section deals with the livestock identification and registration module; while the second sub-section focuses on the livestock tracking module. The last subsection deals with knowledge management and dissemination on livestock theft.

8.5.1. Proposed Solution for Livestock Identification and Registration

This section focuses on the livestock identification and registration module. In this section, a retinal patterns-based biometric system is proposed for the enrolment/registration, identification, verification and proof of ownership of livestock. To aid the design of the proposed retinal patterns-based biometric system, an illustration of the system is provided using block diagram, context diagram, and Entity Relationship Diagram (ERD). The system functionalities are explained by providing the processes and procedures involved when using the system.

8.5.1.1. Retinal Patterns-based Biometric Identification Information System

This section focuses on the proposed retinal patterns-based biometric identification system. In the context of this research study, the proposed retinal patterns-based identification biometric system refers to the automatic identification of an individual animal based on its retinal patterns in the eye. The proposed retinal patterns-based biometric identification system would operate by acquiring biometric data (i.e. retinal patterns) from an individual animal (cow, sheep and goat), extracting a feature set from the acquired data, and comparing this feature set against the template set in the database. Retina based recognition has been found as the most secure identification method used to distinguish individual animals, as established in chapter five. The retina recognition stages including retina image acquisition, feature extraction and classification of the features (Sadikoglu & Uzelaltinbulat, 2016), as illustrated in figure 27 below.

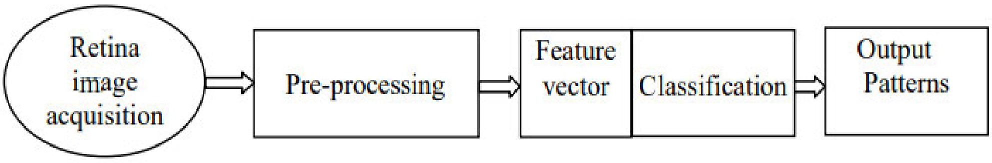


Figure 27: A block diagram of a general retinal recognition system
Source: Sadikoglu & Uzelaltinbulat (2016)

To justify the proposal for the retinal patterns-based biometric system, this section will attempt to address the following basic questions:

- Why employ a retinal patterns-based biometric identification system?
- Who should use the retinal patterns-based biometric identification system?
- How should the retinal patterns-based biometric identification system be used?
- What components should the retinal patterns-based biometric identification system have?
- How should the retinal patterns-based biometric identification system be implemented?

<u>Why employ a retinal patterns-based biometric identification system?</u>

In chapters four and seven respectively, it was established that livestock theft has become an organised crime involving syndicate criminal networks. For example, interview data revealed instances of livestock stolen from the Eastern Cape Province being recovered in the Gauteng Province. In chapter four, it was established that criminal syndicates use sophisticated tactics, tools and equipment to fake livestock branding marks and rebrand stolen livestock. These syndicates then illegally sell the stolen livestock and transport it into neighbouring countries. In the previous section that deals with system design factors and principles, the researcher provided a justification for the need for a permanent, tamper-proof, universal, unique, time-immutable, and collectable identification to control livestock theft in South Africa. A retinal patterns-based biometric identification meets all these factors, as established in chapter five. Several research studies have shown that retina patterns are nearly impossible to fake, as established in chapter five. Regarding animal welfare, a retinal patterns-based biometric system does not pose harm or danger to animals, as established in chapter five. In terms of cost, a retinal patterns-based biometric identification is cost–effective compared to an RFID based system and a microchipped based system. A retinal patterns-based biometric identification method does not require any attachment of a device on an animal. Therefore, regular maintenance and recycling/disposal burdens of devices are eliminated.

The proposed retinal patterns-based biometric system would resolve many fraudulent cases and disputes whereby livestock are stolen from South Africa into neighbouring countries, rebranded, and then brought back to the country. This tamper-proof method would resolve many cases whereby livestock are stolen from one village/region/province and transported into another village/region/province within the country, and then rebranded. Recovery of stolen livestock could be effective and efficient, because all livestock (cattle, sheep and goat) in the country would be linked to their owners along with the farmsteads` geographic coordinates. Accurate livestock population in the country can easily be generated and reported using a retinal patterns-based biometric system.

This is the rationale for proposing a retinal patterns-based biometric identification system. Again, it is not only tamper-proof and robust but also accurate, efficient, reliable and cost-effective. The proposed retinal patterns-based biometric identification system is comprehensive when it comes to registration/enrolment, recording, verification and identification of all cattle, goats and sheep in the country. The system can be 'scaled up' to register, record, verify and identify other similar livestock such as horses, donkeys, and pigs. For this purpose, the system should be coordinated and managed at national level.

In chapters four and seven, it was found that visual ear tags have already been adopted by livestock farmers. Visual tags are cost-effective, easy to apply, and can be visible from a distance. Livestock farmers at their farmsteads can implement visual tags. For effective identification of livestock, the numbering/coding system on visual tags should be unique for each animal, and be integrated with the proposed retinal patterns-based biometric identification. Furthermore, the numbering/coding system on the visual tags should be in accordance with standards, as recommended by WOAH, FAO, ISO, IEEE and ICAR.

<u>Who should use the retinal patterns-based identification biometric system?</u>

To prevent fraud and enforce and data integrity, only qualified and authorised system users should be permitted to undertake the identification and registration of livestock into the national livestock database. The qualified and authorised system users should be agricultural extension officers, animal technicians, and animal production specialists from a competent authority – the Department Rural Development and Land Reform (DALRRD). Other system users such as members of SAPS`s STUs should be assigned a 'read only' permission. The system should be flexible enough to allow farmers to update their basic personal information such as contact details. The context diagram for the proposed retinal patterns-based biometric system depicting the qualified and authorised system users and other necessary entities is shown in figure 28 below. Context diagrams are also referred to as level 0 data-flow diagram. According to University of Waterloo (2022), the purpose of the context diagram is to show the interactions between a system and other actors such as external factors with which the system is designed to interface. It is a diagram that establishes the context and boundaries of the system to be modelled, showing the aspects which are inside and outside of the system, and the relationship of the system with the external entities. It identifies the flows of information between the system and external entities (UCT-CS, 2011).

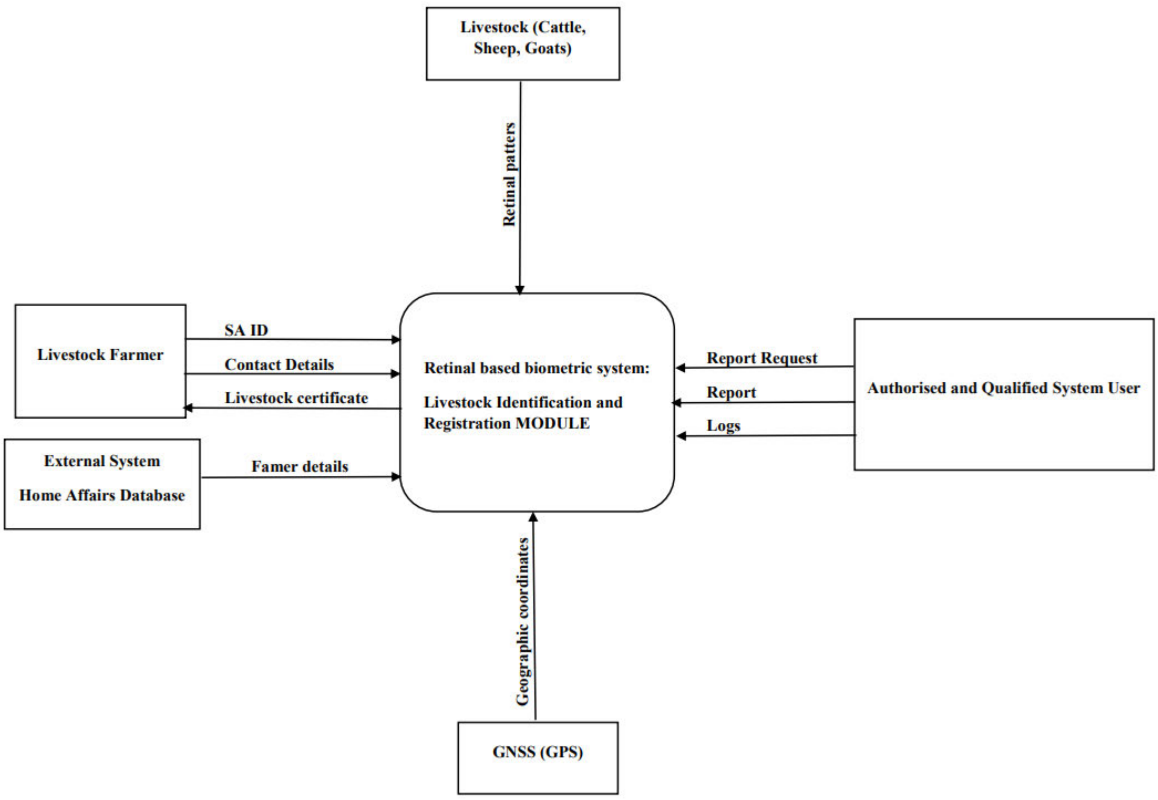


Figure 28: Context diagram for the proposed retinal patterns-based biometric system
Source: Author`s own illustration based on application of DSRM

In the context diagram above, the livestock owner/farmer provides personal information such as ID number and contact details into the system. Retinal patterns are extracted from livestock (cow, sheep, goat), and then recorded into the national livestock system`s database. Using the farmer`s South African ID number, and through the API and ‘look up’ function, livestock owner details such as ID number, name and surname are retrieved from an external system (Home Affairs database). Then this information is recorded into the national livestock system`s database. The ‘logs’ of the qualified and authorised system user such as login time and username are likewise recorded into the system. When there is a dispute/claim over livestock identity, the authorised and qualified system user (e.g. member of SAPS`s STUs) can verify the ownership of livestock against the database information. When there is a need for business intelligence reports such as aggregating livestock population per region or district, the qualified and authorised user can generate these reports from the system. The GPS receiver inside the mobile device receives the coordinates (location and time information) of the farmstead from the GPS satellite. In case of livestock movement, transportation and sale, any registered livestock owners/farmers would be able to automatically generate their official and stamped livestock certificates from the system. The generated certificates would be useful to the police, livestock buyers, slaughterhouses, and auctioners.

<u>How should the retinal patterns-based identification biometric system be used?</u>

For mobility purposes and since the authorised and qualified system users would need to go to farmsteads; mobile devices such as smartphones, tablets, or iPads would be used to record livestock identification into the national database. The justification for the selection of mobile devices is informed by the widespread GSM coverage in the rural areas and the high adoption of mobile phones in the country. The mobile devices would leverage mobile data capabilities for the transfer of data via the GMS network into the national livestock database. To reduce data transfer costs, the DALRRD could negotiate for zero-rated data connectivity with mobile network operators such Vodacom and MTN. Modern mobile devices come with pre-equipped with GPS capabilities; and in this regard, mobile devices would automatically receive geographic coordinates at the farmsteads.

The mobile devices would be equipped with retinal cameras for portable wide field imaging. Some examples of mobile devices equipped with retinal cameras for portable wide field imaging that are available on the market include Nview Volk Optical, ClearView 2 retinal imaging device, and Smartphone Fundus Photography (I-spot Vision, 2022; Volk, 2023; Haddock et al., 2013), as shown in figure 29 below. The advantage of these mobile devices is that they are cost-effective, portable, and offer a convenient method for retinal imaging. The device would be used to take the animal`s (cow, sheep, goat) retinal patterns. The mobile devices would be loaded with a dedicated (specialised) biometric mobile application to enable the recording of livestock identification into the national database. In the context of the proposed retinal based identification biometric system, the specialised biometric mobile application refers to a biometric acquisition software with a specialised retinal engine (algorithm). The retinal engine (algorithm) of the specialised biometric mobile application would extract the animal`s (cow, sheep, goat) retinal patterns, analyse the retinal patterns for quality, and perform a 'match or mismatch' of the retinal template against the national livestock database. The specialised biometric mobile application would be responsible for recording the retinal patterns along with farmer details and other necessary data into the national livestock database. An example of the relevant and suitable biometric acquisition software for national and large-scale projects available on the market is MegaMatcher ABIS 12. The MegaMatcher ABIS 12 software has many features and capabilities that make it qualify for national and large-scale projects. Its features and capabilities include quality assessment of retinal patterns, integrating with cloud-based platforms, customization, scalable and modular architecture. Moreover, it provides fast matching of retinal patterns in verification, identification and duplication modes (Neurotechnology, 2022).

Figure 29: Mobile device equipped with retinal camera for portable wide field imaging
Source: I-spot Vision (2022); Optibrand (2022); Volk (2023); Haddock et al. (2013)

In terms of the large-scale frequency of livestock identification and registration, this process would be conducted once-off every year or every two years. This is because it usually works out that cows, sheep and goats usually give birth every 12-14 months. For the purposes of new livestock entering the country, the owner of livestock would have to notify the DALRRD, so that new livestock can be registered into the national database and be assigned a unique identification.

Of what components should the retinal patterns-based identification biometric system consist?

As already stated in the previous sections, in the context of this research study, a retinal patterns-based biometric system is a pattern recognition system that operates by acquiring retinal patterns from an animal`s (cow, sheep, goat) eye, extracting a feature set from the data acquired, and comparing this sample against an earlier registered template (ITU, 2009). The proposed retinal patterns-based biometric system has certain main functional components, which include:

Storage entity: This refers to the biometric data samples (templates) of the enrolled livestock that are linked or integrated in a database with the identity information of the corresponding livestock owners (Kumar et al., 2018; ITU, 2009). In the context of this research study, the biometric data samples (templates) are retinal features, also known as retinal patterns.

Data repository: This refers to the data storage entity to securely store biometric data for comparison. Depending on type of application, the template (sample data) may be stored in the database or on 'token' such as USB flash drive or smart card (Kumar et al., 2018; ITU, 2009). In the context of this research study, this refers to the national livestock database.

Biometric sensor (reader) device: This refers to an electronic device with pre-processing capabilities to capture the biometric sample data from an animal as input data (Kumar et al., 2018; ITU, 2009). In the context of this research study, the biometric sensor device is a mobile device (smartphone, tablet or Ipad) loaded with a specialised mobile application and equipped with retinal camera for portable wide field imaging.

Biometric software: This refers to a specialised software to convert the scanned biometric data into a standardized digital format and to compare match points of the observed data with stored data (Kumar et al., 2018; ITU, 2009). In the context of this research study, this refers to the specialised mobile application described in section 8.5.1.1.3 above.

Comparison process: This refers to process of evaluating the similarity between reference template and captured sample, and then calculating a matching score. In the context of this research study, this refers to an algorithm embedded into the mobile application.

Decision function: This is a sub-process of the comparison process that decides if the data sample matches with the reference template. This sub-process is part of the algorithm that is embedded into the mobile application.

Telebiometrics: This refers to the communication channels needed to support the above main components. These communication channels can be wired or wireless telecommunication environments and use private or public networks, including the Internet. In the context of this research study, this refers to GMS networks (3G, 4G, etc.).

Having described the biometric components above, the researcher will now create the block diagram of livestock identification and registration, as illustrated in figure 30 below. According Miro (2023), a block diagram is an illustration of a system in which the principal parts or functions are represented by blocks connected by lines that show the relationships between the blocks. A block diagram is used to visualize the functional view of a system (Lynch, 2023). The block diagram shown in figure 30 illustrates the main functional components of livestock identification module. The block diagram constitutes three modes: (i) pre-enrolment mode, which deals with retrieving the details (ID number, name, surname, etc.) of the livestock owner from an external system (Home Affairs national database); (ii) enrolment mode, which focuses on registration (recording) of biometric sample data (retinal patterns) and other associated important data into the national livestock database; and (iii) verification mode and identification mode, which together focus on searching and recognising an individual animal from an entire enrolled livestock population.

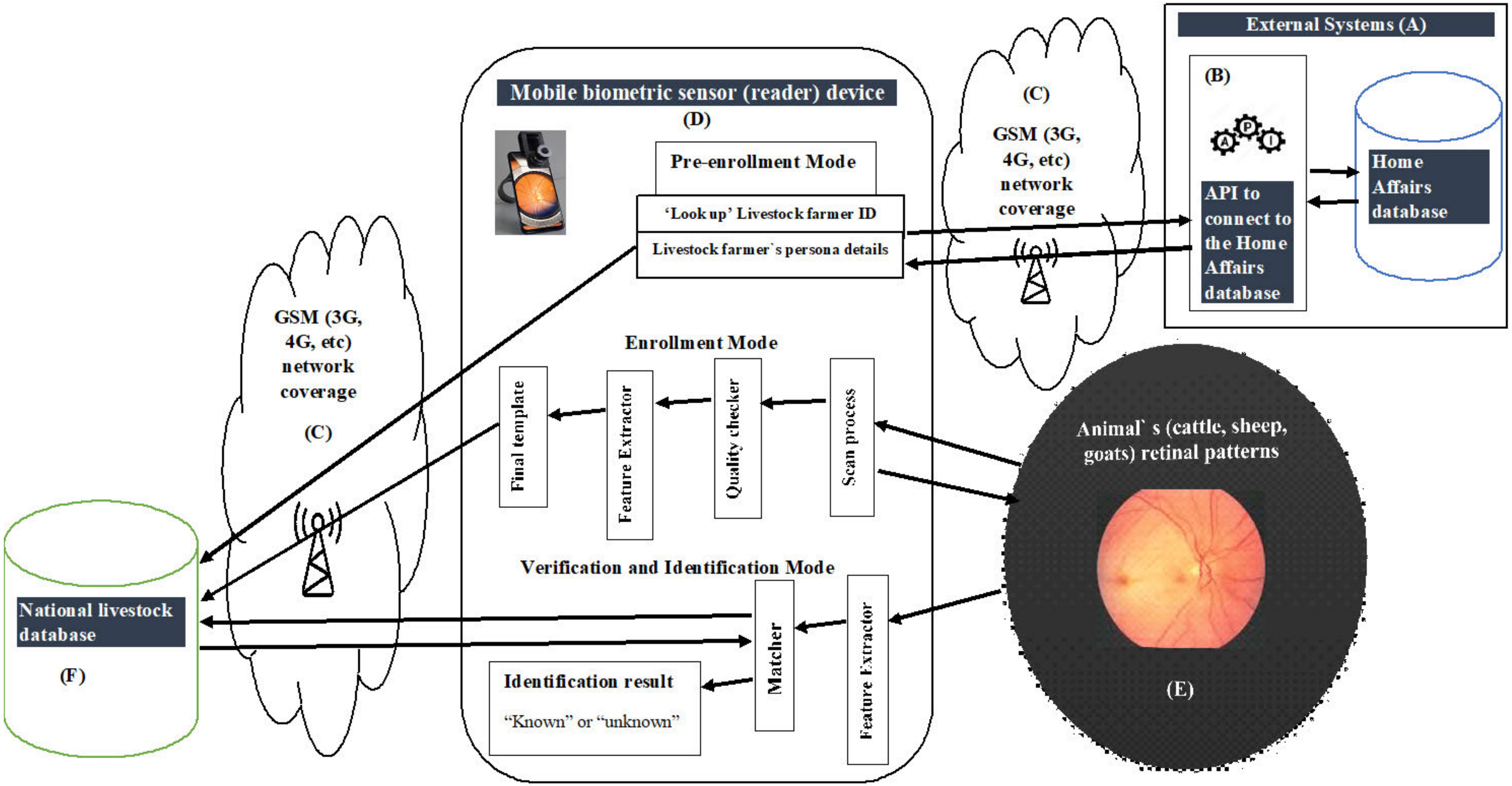


Figure 30: Block diagram of the proposed retinal patterns-based information biometric system.
Source: Author's own conceptualisation based on biometric components

The block diagram above has several principal parts:

Block (A) represents an external system, which ‘houses’ the Home Affairs national database (National Population Register). This database stores and manages all the information pertaining to the national population of the country. In the pre-enrolment mode, this automates the process and ensures that the verifiable and correct details of a livestock owner are recorded into the national livestock database. When the details such as name or surname are edited in the National Population Register, the same details should automatically reflect in the national livestock database.

Block (B) represents an API. An API is application program interface. It is used in mobile applications just like it is used in web applications. An API allows the mobile applications to access an external database or another application or platform. The mobile app in the mobile device would connect to the external system (Home Affairs national database) through the API.

Block (C) represent cellular network (GSM/3G/4G/5G, etc.). This is a communications channel needed to support the transfer of data between the mobile devices and database system.

Block (D) represents the biometric sensor device. The device is loaded with a specialised biometric mobile app. The device is also equipped with retinal camera for portable wide field imaging. The device is responsible for capturing and recording retinal patterns along with details of livestock owner/farmer into the national livestock database. Through the biometric acquisition software loaded on the device, the device is also responsible for comparing and verifying the retinal patterns during both the enrolment identification phases, respectively.

Block (E) represents biometric sample data (template) extracted from an animal (cow, sheep and goat). This is a unique pattern found in every animal.

Block (F) represents the national livestock database. This database system is responsible for securely storing livestock details (e.g. retinal patterns, unique codes, etc) and the associated data such as livestock owner/farmer details (e.g. name, surname, ID number, etc.) and farmstead details (e.g. location in coordinates, unique number, etc.). The national livestock database should be distributed and cloud-based to enable scalability, elasticity and ubiquitous access. Some examples of cloud-based services that can be used to deploy and implement the proposed national livestock database include Amazon Web Services, Google Cloud Spanner, Microsoft Azure, and SITA`s Mainframe Hosting (Datsenko, 2024; SITA, 2017b).

In the above block diagram, the livestock identification and registration into the national database involves the following processes and procedures:

Step 1: Qualified and authorised system user logs in to the specialised Mobile App

Step 2: Mobile Apps shows the Menu items

Step 3: User selects New Registration from the Menu

Step 4: User enters or scans South African Identity Number (ID) of the livestock owner into the system.

Step 5: Mobile App connects to the Home Affairs database through the Application Programming Interface (API) to automatically get/retrieve livestock owner details from Home Affairs database.

Step 6: Enter Contact Details (*optional)* of the livestock owner

Step 7: Scan the right eye of the animal. Scan left eye of the animal

Step 8: Retinal patterns: The algorithm in the mobile App (biometric acquisition software) automatically does the 'quality check' and feature extraction. The feature extraction should be in accordance with standards as recommended by IEEE.

Step 9: Mobile App automatically checks if the feature extraction (retinal pattern) already exists or not in the national livestock database. If the feature extraction does not exist, mobile records the feature into the livestock national database.

Step 10: Unique animal identification code that is linked to the unique Retinal pattern is auto-generated from the national livestock database. This code should be in accordance with standards, as recommended by IEEE. This unique animal code can be printed onto a visual ear tag. It can also be used as a branding mark.

Step 11: Repeat Step 7 if more animals of the same owner are to be scanned.

Step 12: With the GPS capabilities on the mobile device, mobile App automatically records the geographic coordinates of the farmstead (property) where livestock are kept into the national livestock database.

Step 13: Unique identification farmstead code (property code) where animals are kept is auto-generated from the national livestock database. This code is linked to geographic coordinates recorded in step 12. This farmstead code should be in accordance with international/ national standards.

Step 14: Unique reference number for the owner is auto-generated from the national livestock database. Livestock owner can use this number for all correspondences related to livestock identification, tracking, and lost/stolen livestock.

Step 15: User presses the option 'done'.

The researcher will now create the Entity Relationship Diagram (ERD) that represents the national livestock database. An ERD is a diagram that provides entity framework infrastructure as well as an explanation of the logical structure of a database. An ERD is created based on three basic concepts: entities, attributes and relationships. Hence, it displays the relationship of entity sets stored in a database. Figure 31 illustrates the ERD for the national livestock database. The nature of this database is relational due the structured data that need to be stored and manipulated. For the purposes of illustration, there are six entities in the database: Farmers, Livestock, Farmsteads, Livestock_Farmsteads, System_Users, and Logs. For the purposes of illustration, only the main attributes of the selected tables/entities in the database are shown; the database can be scaled up to include as many tables and attributes as possible. The database entities and the main attributes (fields) are summarised in table 34 below.

Table 34: Entities and main attributes for the national livestock database

Entities	Main Attributes	Data Type	Purpose of Attribute and Values (Data) to Store	Primary Key	Foreign Key	Unique Field	Composite Key
FARMERS	Farmer_ID.	Varchar.	To store the primary key values for the entity to uniquely identify each row in the table.	Yes.	No.	Yes.	No.
	SA_ID.	Numeric.	To store the South African Identity Number.	No.	No.	Yes.	No.
	Name.	Varchar.	To store the livestock farmer`s (owner`s) names.	No.	No	No.	No.
	Surname	Varchar.	To store the livestock farmer`s (owner`s) surnames.	No.	No.	No.	No.
	Phone_Number	Varchar.	To store the livestock farmer`s (owner`s) phone number.				
	Ref_No.	Varchar.	To store a reference number that can be used by the farmer/owner on matters related to livestock theft and reporting of livestock.	No.	No.	Yes.	No.
LIVESTOCK	Animal_ID.	Varchar.	To store an electronic identification of an animal. To store the primary key values for the entity in order to uniquely identify each row in the table.	Yes.	No.	Yes.	No.
	Animal_Type	Varchar.	This means cow, sheep or goat.				
	Retinal_Template (right eye).	Binary.	To store an electronic image of retinal template.	No.	No.	Yes.	No.
	Retinal_Template (left eye).	Binary	To store an electronic image of retinal template.	No.	No.	Yes.	No.
	Retinal_Code (right eye).	Varchar.	To store a unique code associated with retinal template (right eye).	No.	No.	Yes.	No.
	Retinal_Code (left eye).	Varchar.	To store a unique code associated with retinal template (left eye).	No.	No.	Yes.	No.
	Farmer_ID.	Varchar	To be link the two entities ‘Farmers and Livestock’ to create a 1:M relationship between the two entities.	No.	Yes.	Yes.	No.
FARMSTEADS	Property_ID.	Varchar.	To store the primary key values for the entity in order to uniquely identify each row in the table.	Yes.	No.	Yes.	No.
	Property_Number	Varchar.	To store the South African farmstead number.	No.	No.	Yes	No.
	Geo_Coordinates.	Spatial Reference Identifier(SRID),	To store the geographic coordinates of South African farmstead.	No.	No.	Yes.	No.
LIVESTOCK_AND _FARMSTEADS	Property_ID,	Varchar.	To store the foreign key value as Property_ID.			Yes	Yes.
	Animal_ID	Varchar.	To store the foreign key value as Animal_ID.			Yes	Yes.
QUALIFIED SYSTEM_USERS	User_ID.	Varchar.	To store the primary key values for the entity in order to uniquely identify each row in the table.	Yes.	No.	Yes.	No.
	SA_ID.	Varchar.	To store the South African Identity Number.	No.	No.	Yes.	No.

Entities	Main Attributes	Data Type	Purpose of Attribute and Values (Data) to Store	Primary Key	Foreign Key	Unique Field	Composite Key
	Name.	Varchar.	To store the names of the system user.	No.	No.	No.	No.
	Surname.	Varchar.	To store the livestock surnames of the system user.	No.	No.	No.	No.
	Username.	Varchar.	To store the username of the system user.	No.	No.	Yes.	No.
	Password.	Varchar.	To store the password of the system user	No.	No.	No.	No.
	User_Level.	Varchar.	To identify the role (user level and type) of the system user.	No.	No.	No.	No.
LOGS	Log_ID.	Varchar.	To store the primary key values for the entity in order to uniquely identify each row in the table.	Yes.	Yes.	No.	No.
	User_ID.	Varchar.	To store the foreign key value as User ID.	No.	Yes.	Yes.	No.
	Date_Time.	TimeStamp.	To store the date and time of log.	No.	No.	No.	No.
	Activity.	Varchar.	To store and indicate the event (activity) carried out by the system user.	No.	No.	No.	No.

Source: Author`s illustration

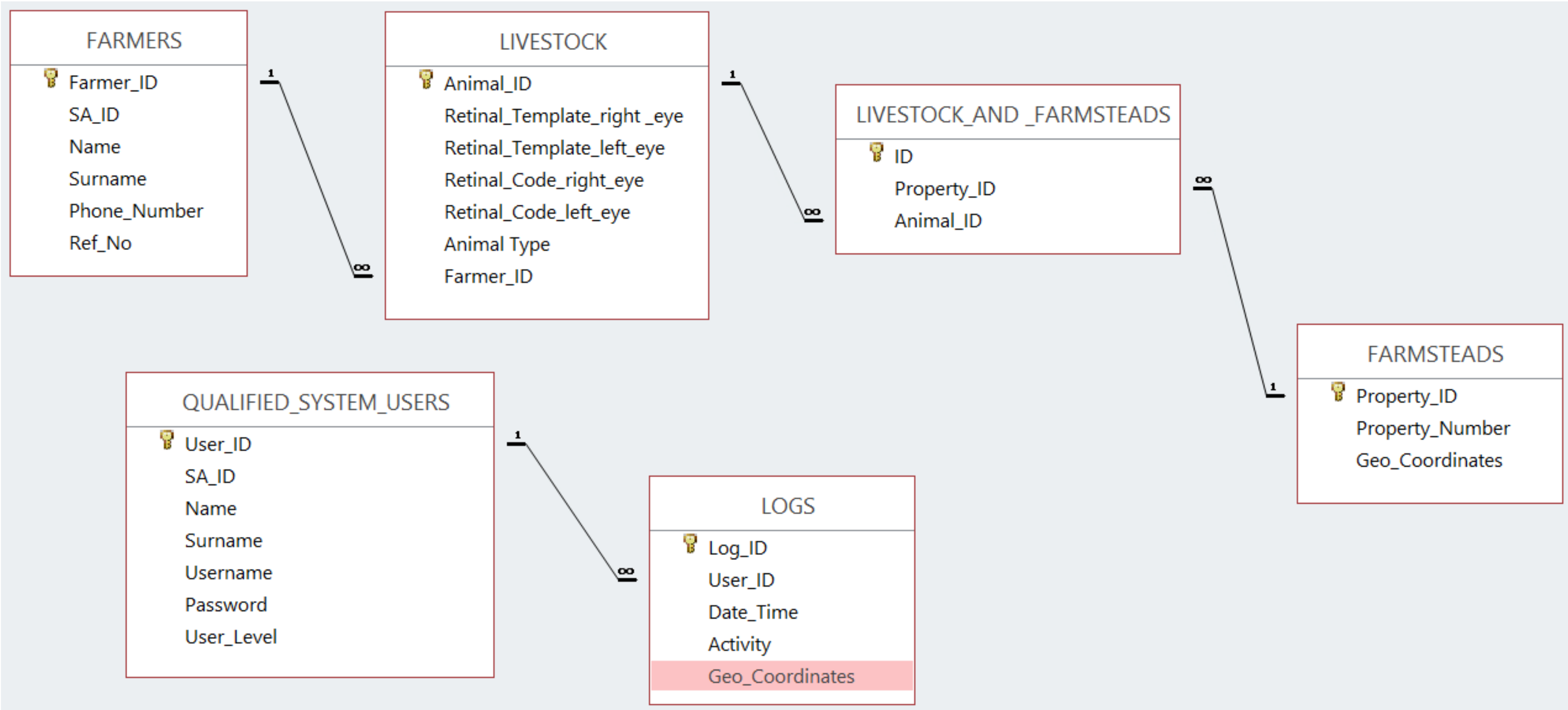


Figure 31: Entity Relationship Diagram (ERD) for the national livestock database
Source: Author's own illustration

In the ERD the above, we can see that the relationship between the entities ***Livestock_Farmers*** and ***Livestock*** is that of one-to-many, while the relationship between **Livestock** and ***Farmsteads*** is that of many-to-many. This means a livestock farmer can own more than one cow or sheep or goat; while many animals (cows, sheep or goats) owned by the farmer can be kept at different farmsteads. Since there is a many-to-many relationship between the entities ***Livestock*** and ***Farmsteads***, the entity ***Livestock_Farmsteads*** serves as a bridge entity between the entities ***Livestock*** and ***Farmsteads***. There is a one-to-many relationship between the entity ***Logs*** and ***System Users*****.**

How should the retinal patterns-based biometric identification system be implemented?

Since DALRRD`s core business is not ICTs or IT, the DALRRD may not have the technical capacity to manage and implement the national livestock database. For this DALRRD`s limitation, it is suggested that the SITA should manage and implement the national livestock database. The SITA`s core mandate is to consolidate and coordinate the State's information technology resources to achieve cost savings through scale, increase delivery capabilities and enhance interoperability. The SITA has ICT capabilities, including cloud database hosting, application development, application maintenance, network management, service management, and management of architecture, standards and specifications. The SITA is positioning itself as the national cloud service provider for the South African government through a focused cloud programme to provide a common and secure Government private cloud to assist Government departments to consolidate their solutions, provide efficiency, interoperability and collaboration (SITA, 2017a). With the SITA`s ICT capacities, it is suggested that the national livestock database should be implemented as a cloud based and distributed database. A cloud based implementation approach would enable the defined performance measures (responsiveness, data storage capacity, scalability, required throughput, availability, etc.) for the national livestock database.

Other requirements for the implementation of retinal patterns-based biometric identification information system are devices and software for capturing and recording livestock data, communications network for data transfer, and trained and qualified system users. As described in section 8.5.1 there are some existing software that can customised for large-scale and national retinal patterns-based biometric identification for livestock. Since it would take a long time and be expensive to develop a software for retinal patterns-based biometric identification from 'scratch', it is suggested that such software be outsourced and customised accordingly. This will minimize the risks and reduce the costs. The existing data communications network in the farming communities and rural areas is mainly GSM, hence the suggested data communications network for data transfer is cellular based network, as explained in the previous sections. In the previous section, a suggestion on trained and qualified system users was provided.

The governance and oversight of the retinal patterns-based biometric system and national livestock database should be responsibility of the DALRRD, since one of the functions of this Department is to manage livestock identification in the country. The DALRRD in partnership with ARC, SITA, CSIR and the SAPS`s STUs should be custodian of the national livestock database, and retinal patterns-based identification biometric system. The suggestion is informed by the national mandate given to the DALRRD, as discussed in chapter two. Furthermore, in chapter three, it was established that the DALRRD is responsible for the registration and enforcement of livestock identification (branding and tattooing) of all livestock in the country. ICT capabilities and resources inform the suggestion about the two state-owned entities, SITA and CSIR. The two state-owned entities pose cloud capabilities and resources. The ARC is well experienced with DNA forensics, and has research and development capabilities. The SAPS`s STUs have experience, resources and capabilities in investigating livestock theft cases.

The SITA should also technically manage the hardware/device configuration, and software customization and configuration on behalf of DALRRD. The DALRRD should also partner with other institutions such as Red Meat Organisation. A collaboration and partnership for national livestock database will minimize the implementation risks, while also reducing the management and implementation costs. A pilot project of the national livestock database integrated with retinal patterns-based biometric identification information system could be first implemented in the livestock theft hotpot areas, before rolling out the project to the entire country. Such a pilot project would mitigate risks, while providing quicker implementation, testing with an engaged audience, refining the system, spurring of new ideas, and real feedback.

The animal welfare factor and the protection of the stakeholders against potential dangers from livestock during the capturing of retinal patterns need to be considered. To protect the welfare of the stakeholders and animals, the immobilisation of the head of livestock (especially cattle), to capture their retinal patterns would require a combination of physical restraint, proper equipment, and techniques. This would also ensure the safety and comfort of the animals. In the country, cattle dipping facilities, cattle crushes and cattle presses are available and being used by farmers. These facilities and equipment can be used to safely restrain the head of livestock (especially cattle), when capturing the animals` retinal patterns. For instance, in 2011, the Eastern Cape province reported having over 2,000 dipping facilities (Department of Rural Development and Agrarian Reform, 2011). Similarly, the 2017 report on census of commercial agriculture indicates that there were about 944 cattle crushes and cattle presses being used in the commercial farming sector (StatsSA, 2020).

8.5.2. Proposed Solution for Livestock Tracking

This section focuses on the livestock tracking module. Three livestock tracking approaches are proposed in this section, namely: (i) technological crowdsourcing known as mobile crowdsourcing - integrated with a panic button, (ii) drone use integrated with cloud services, and (iii) remote-activated camera traps integrated with cloud services. On proposing these technologies for livestock tracking, this section will attempt to address five basic questions: “why the proposed technology?”, “who should use the technology?”, “how should the technology be used?”, “what/which sensor technologies, components, features and functionalities should be embedded into the proposed technology?”, “and what benefits/value would the propose technology offer?”. The first part of this section deals with the technological crowdsourcing known as mobile crowdsourcing. The second subsection focuses on drone use integrated with cloud services and remote-activated camera traps integrated with cloud services.

8.5.2.1. Technological Crowdsourcing (Mobile Crowdsourcing)

There are many definitions of crowdsourcing in the literature. The common elements of crowdsourcing definitions found in the literature include: sourcing model, task performance, problem solving, contributions, participative online activity, web and social collaboration techniques; involvement of individuals of varying knowledge, heterogeneity, voluntary undertaking, and some kind of reward. In a broader/general context, the concept of crowdsourcing refers to a sourcing model in which there is an involvement of a large group of dispersed participants contributing services, goods, micro-tasks, finances, voting, views, observations, or ideas for a common cause, issue, challenge or problem. In the context of this research study, the concept of crowdsourcing refers to sourcing views, observations and ideas from livestock stakeholders for the common cause or problem. The common cause or problem is livestock theft in the country.

Technological or mobile crowdsourcing exploits the advantages of mobility, context-awareness and mobile sensing, while also leveraging cellular technology such as the GSM network (3G/4G/5G). There are seven common elements of mobile crowdsourcing definitions that can be observed from the literature: dispersed participants, data collection, data sharing, data processing, mobile devices, and cloud. According to Mahmud & Aris (2015), Fuchs-Kittowski and Faust (2014), mobile crowdsourcing refers to a group of people (dispersed participants) who voluntarily collect and share data using widely available mobile devices such as feature (basic) phones, smartphones, tables and IPads to solve a problem. This collected and shared data can then be processed and provided via a data-sharing infrastructure to third parties who are interested in integrating this data.

<u>Why use technological crowdsourcing (mobile crowdsourcing)?</u>

This study has found that livestock stakeholders are organised in two primary ways when it comes to the 'fight' against livestock theft in South Africa. These are (i) community imbizo (simply meaning gatherings), and (ii) community forums such as Masifinisane (simply means helping each other). The knowledge provided in chapter five revealed that some farming communities are part of community-based safety and security operations; for example, Operation Servamus. The literature also revealed that some commercial farming communities were using social media and instant messaging to post information about stolen livestock. These findings imply that some communities rely on some form of community structures, programmes or initiatives to safeguard their livestock against theft. The crowdsourcing concept is based on the idea of attracting and involving the desired participants to stimulate relevant contributions or solutions to a common cause, concern, problem, challenge, task or issue. For these purposes, it is clear that farming communities are 'embracing' the concept of crowdsourcing. However, the identified community efforts are 'fragmented' and operate on a very small scale. These include a single farm community, smallholding community or two farming communities. There is no national, provincial, regional, district or local (municipal level) coordinated and comprehensive information sharing and networking platform to deal with livestock theft in the country.

In chapter seven, various 'actor-networks' related to crowdsourcing emerged. Some of the emerged 'actor-networks' include notification alerts through mobile devices, collaborative livestock theft reporting systems, online community forums, and a connected livestock society. These 'actor-networks' constitute diverse actors, including farmers, police, and community forums; as established in chapter seven. Also, in chapter seven, the researcher participants` suggestions to form intelligence functions, better communications, information sharing/exchange, and closer relationships and collaborations towards the fight against livestock theft. The suggestion on closer cooperation among and between stakeholders, including community patrols and the use of informants likewise emerged in chapter seven.

Research studies on crowdsourcing in Africa that were conducted by Dahunsi et al. (2021), Phuttharak & Loke (2018) and Chuene and Mtsweni (2015) revealed several crowdsourcing initiatives in various applications. Among these are finance, government, health, and the social arena. Most of these crowdsourcing initiatives have been implemented using web based technologies. There is limited research and use cases (business cases) on mobile crowdsourcing, particularly for livestock management and theft control. In this regard, no mobile crowdsourcing model, approach, strategy, or system on livestock theft control/management for the South African context was found in the literature. Therefore, the proposed technological crowdsourcing (mobile crowdsourcing) can be viewed as 'one of a kind' in South Africa to deal with livestock theft.

Based upon the foregoing evidence-based findings, the researcher proposes a national, holistic and coordinated technological crowding approach as an alternative strategy for controlling livestock theft in the country. Due to the widespread GSM coverage in the rural areas and common adoption of mobile phones in South Africa, the proposed technological crowdsourcing approach would leverage GSM network (3G, 4G, etc.) and mobile phone technology. Therefore, the proposed technological crowding approach is based on the concept a mobile crowdsourcing system.

The proposed mobile crowdsourcing approach would enable the affected network actors to collaborate and raise alarm so as to assist each other in prohibiting perpetrators from stealing livestock. The proposed holistic and national ICT-based crowdsourcing approach would enable effective and efficient collaboration between the farmers, police, government, farming communities, and force multipliers. Through the proposed holistic and national ICT-based crowding approach, instant community linkages would be integrated and streamlined. This would help speed up the process of tracking and recovering stolen livestock. The perpetrators might be discouraged to indulge in theft of livestock if they are aware of the crowdsourced 'synergy' among network actors. With such a system in place, livestock theft could be controlled in the country.

Who should use the proposed mobile crowdsourcing system?

In chapter three, the key actors and their interests in the fight against livestock theft in the country were described. In chapter seven, other actors such as rural safety officials, herdsmen, abattoirs, auctioneers, slaughterhouses emerged. With this information in mind, the researcher suggests that all these identified actors should be part of the proposed technological crowdsourced system. In the context of this research study, crowdsourced participants refer to livestock farmers, farming communities, community police forums, safety officials, herdsmen, abattoirs, auctioneers, slaughterhouses, buyers, sellers, and neighbourhood watches. The role of the crowdsourced members is three-fold: (i) to report stolen, stray, lost or missing livestock through the mobile crowdsourcing system; (ii) provide information (leads, hints, tips) about stolen, stray, lost or missing livestock; and (iii) in case of emergency, the livestock farmers and farming communities would use the panic button integrated with the cloud processing layer to alarm community forums, police, force multipliers and other crowdsourced participants. Figure 32 below shows the context diagram illustrating the various actors that interface with the proposed mobile crowdsourcing system.

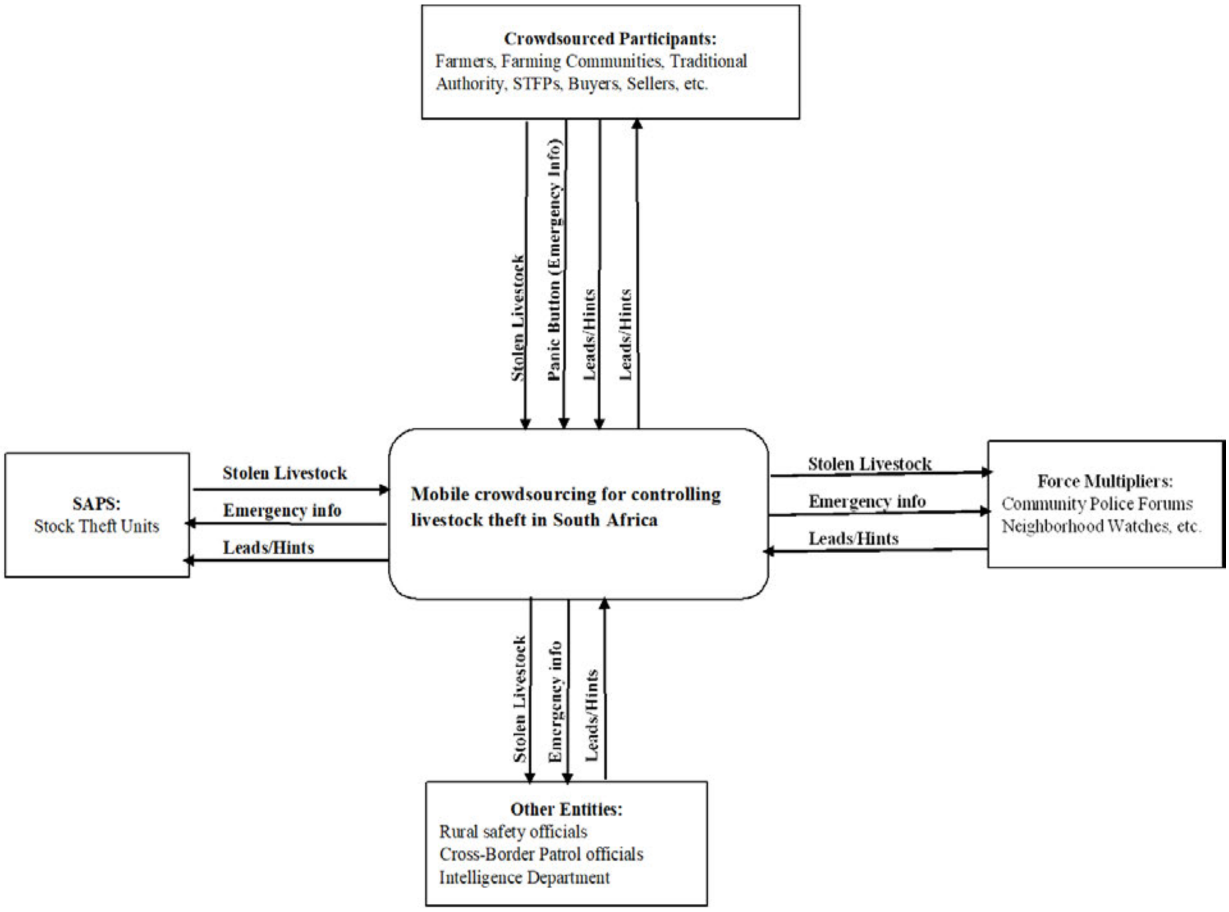


Figure 32: Context diagram for the proposed mobile crowdsourcing system
Source: Author`s evidence-based illustration

<u>What are the components of the proposed mobile crowdsourcing system and how should it be used?</u>

To answer this question, the researcher will first summarise and contextualise the key aspects of a mobile crowdsourcing system as provided by Phuttharak & Loke (2018). The researcher will then apply these key aspects to develop the architecture of the proposed mobile crowdsourcing approach. According to Phuttharak & Loke (2018), a mobile crowdsourcing system has several principal aspects. These aspects are summarised in figure 33 below.

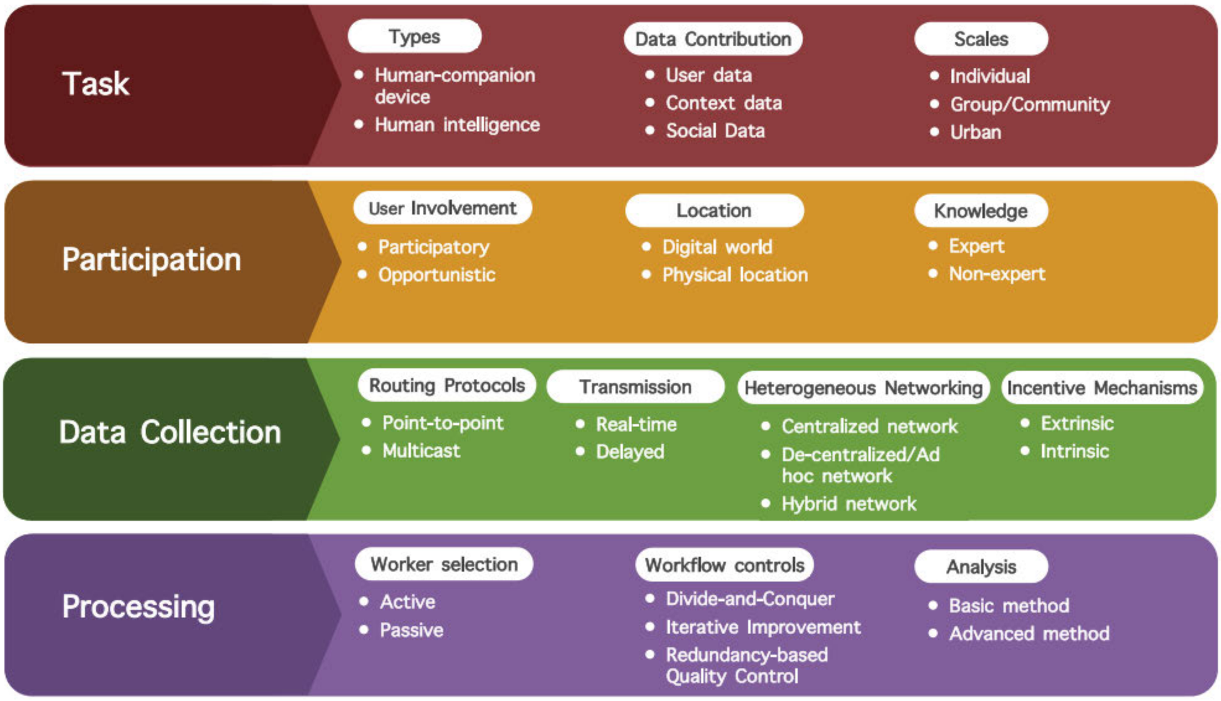


Figure 33: Key aspects of mobile crowdsourcing system

Source: Phuttharak & Loke (2019)

Task: This refers to human intelligence required tasks that employ mobile devices to collect and share user data, context data and social data (Phuttharak & Loke, 2018). One of the important asks is to report stolen livestock, missing/lost livestock and stray livestock. Other important tasks include provide information (text, audio, pictures, videos, etc.) about stolen livestock and smuggling of livestock into the neighbouring countries. Providing information about illegal sale of livestock and sale of stolen livestock is also important, because sometimes stolen livestock are sold to the slaughterhouses, auction houses, etc. The proposed mobile crowdsourcing approach is based on stakeholder community participation. Anyone in the stakeholder community can provide information about stolen or stray livestock as well as illegal sale of livestock. Another important feature of the proposed mobile crowdsourcing system is the mobile app based panic button. With this panic button, anyone crowdsourced can simply press the panic button on the mobile phone in case of a livestock theft. The emergency information in the form of alerts would be automatically directed to the nearby crowdsourced members, local SAPS, local traditional authorities; and local force multipliers such as community police forums, neighbourhood watch, private security companies, and reservists. The provided information would assist community mobilisation, fast-tracking the recovery of stolen livestock. Since the proposed crowdsourcing approach is a coordinated, holistic and national system, information sharing/exchange would not be limited among local 'crowds' but would be of cross-community, inter-regional, and inter-provincial dimensions.

Participation: In terms of user involvement, the proposed mobile crowdsourcing model is based on active participatory involvement 'crowd' individuals that utilise mobile devices to contribute information (Phuttharak & Loke, 2018). The relayed information is about stolen, missing and stray livestock, respectively. With technological convergence such as GPS, cameras, embedded onto mobile devices, the information can be in the form of pictures, audio, text, videos or a combination of any of these formats. With the ubiquity of interactive mobile devices, the 'crowd' members would be able to provide information anywhere and at any time. In terms of knowledge, using a mobile device to provide information about stolen/missing/lost/stray livestock, one need not be an expert in a particular field. According to GeoPoll (2022), about 95% of the adult population are using mobile phones, while 91% of all phones in the country these days are smartphones.

Data Collection: Routing protocol refers to the propagation strategy to disseminate the reported information (e.g. text, voice messages, videos, pictures, etc.) about the specific stolen livestock. The routing protocol known as point-to-point is not suitable for the proposed mobile crowdsourcing approach because it limits communication to only two mobile peers (nodes or endpoint) at a time. The more suitable routing protocol would be multicast communication, because with this strategy communication is accomplished through one-to-many connections among mobile peers (nodes or endpoint) at a time (Phuttharak & Loke, 2018). In a practical implementation scenario, this demonstrates that information from one crowdsourced member about stolen livestock can be simultaneously forwarded to many other crowdsourced members. Therefore, crowdsourced members can respond to the sent message at any time. With the multicast routing protocol and existing GSM/3G/4G/5G network coverage in the country`s rural areas, information about stolen livestock can be transmitted among crowdsourced participants, SAP`s STUs, and other relevant stakeholders in real-time. In terms of an incentive mechanism, a cash reward model adopted by the country`s SAPS could be incorporated into the proposed mobile crowdsourcing system.

Processing: As previously mentioned, a typical mobile crowdsourcing system consists of a platform residing on the cloud and mobile devices. Mobile devices transmit data (tasks) to the cloud database or to the other mobile devices via cellular networks (3G/4G/5G, etc.) (Phuttharak & Loke, 2018).

Having created the context level diagram, and described and contextualised the principal aspects of mobile crowdsourcing, the researcher next describes processes and procedures involved in the proposed technological crowdsourcing approach.

Step 1**:** The livestock farmer/keeper/victim uses a mobile device to report stolen livestock to a local SAPS or local traditional or community authorities. Reporting can be done through USSD, IVR, specialised mobile app, or bot embedded in a popular mobile network such as WhatsApp. The reported information can include details such as the type of livestock (i.e. cattle, sheep or goat), day of theft, place/area where theft occurred, and livestock pictures (if available). Some of the most important components of the crowdsourcing system are routing sub-systems, routing protocols and a backend server. With the routing sub-systems, routing protocols and backend servers, the information about stolen livestock would be automatically shared with the crowdsourced members. When this information is received by SAPS, a case number would be generated from an external system known as Crime Administration. Similarly, any crowdsourced member can report the seemingly stray livestock, suspicious theft, illegal sale of livestock and sale of stolen livestock. Once reported, this information would be automatically shared with the crowdsourced members. To derail immediate theft of livestock, the livestock farmer/keeper/victim can simply press the panic button on the mobile phone. This emergency information would be automatically shared with nearby crowdsourced members as previously described.

Step 2: Crowdsourced members, including but not limited to community police forums, neighbourhood watch, private security companies and reservists can provide leads, tips or hints about stolen livestock. SAPS can also source information from external sources such as social media, cross-border control systems, camera traps, etc. With the routing sub-systems, routing protocols and backend servers, the leads, tips or hints about stolen livestock would be automatically shared with the crowdsourced members and SAPS. Because the proposed crowdsourcing approach is based on integrating all the ‘crowd’ participants across the country, a member of STUs located in Limpopo Province would be able to view the information from a crowdsourced member in the Eastern Cape Province, for example. In addition, the crowdsourcing approach would facilitate rapid information exchange among the country`s three law enforcement units: STUs, intelligence unit, and cross-border patrol unit. With this synergy, crowdsourced members and SAPS can always be on the alert.

The researcher next creates the technical architecture of the proposed technological crowdsourcing approach, as illustrated in figure 34 below. In principle, the proposed mobile crowdsourcing architecture is a hybrid architecture: a combination of centralised architecture and decentralised architecture. Part A refers to a centralised architecture, where all gathered data from the crowdsourced participants is transmitted via GSM/3G/4G/5G network to the cloud server for storage, forwarding and processing purposes. This part has three layers: (i) End-user Layer, (ii) Connectivity and Networking Layer, and (iii) Crowd Processing Layer. Part B refers to the decentralised architecture, where crowdsourced participants can directly exchange information about stolen/missing/lost/stray livestock without the information going through the cloud sever. The first few paragraphs provide an explanation of Part A. The last paragraph explains Part B.

The End-user Layer consists of diverse crowdsourced mobile phone users, including livestock farmers, traditional authorities, farming communities, members of stock theft preventative forums, slaughter houses, animal pound keepers/officials. Members of STUs (SAPS) are also within this layer. The country`s cross-border patrol officials and intelligence officials can also be included in this layer. These participants can use mobile devices, such as smartphones, basic feature phone, and tablets, to interact with the crowdsourcing system. They can report incidents of livestock theft, provide updates, and receive notifications about potential threats or recoveries. This layer is crucial as it forms the backbone of the crowdsourcing aspect, relying on the community's active involvement to track and report stolen livestock efficiently.

The aspects of the Application Layer would be integrated with the End-user Layer. These would include mobile applications designed specifically for livestock tracking and crowdsourcing. These apps would allow mobile users to report theft incidents, send SOS alerts, and engage with the community through social media integration and online forums. Incident reporting systems enable users to provide real-time updates and receive alerts about nearby thefts. Community engagement tools can help foster collaboration among users, making it easier to share information and coordinate efforts to recover stolen livestock. This layer is essential for facilitating user participation and ensuring seamless interaction with the mobile crowdsourcing system.

A crowdsourced mobile user can report stolen/missing/lost/stray livestock using a mobile service (e.g. USSD code, IRV, specialised app, or bot) on the mobile device. Upon reporting, this information is then transmitted to the cloud-based crowd server through the Connectivity and Networking Layer, the GSM/3G/4G/5G networks in particular. The cloud-based crowd server thereafter routes the reported information about stolen/missing/lost/stray livestock to nearby and relevant crowdsourced mobile users, local traditional authorities, and local SAPS. Any crowdsourced member who has information about the reported stolen, missing, lost, or stray livestock can respond via USSD code, IRV, app, or bot on the mobile device.

It is worth noting that the Connectivity and Networking Layer is not limited to GSM/3G/4G/5G networks, as members of STUs (SAPS) may be connected to the mobile crowdsourced system from their workplace via Wi-Fi routers, or Ethernet-based gateways. The cloud-based 'crowd' server may the connected to the Internet via Wi-Fi routers, Ethernet-based gateways. The main purpose of the cellular network (GSM/3G/4G/5G) is to serve the mobile users (crowdsourced participants). The Connectivity and Networking Layer comprises the wireless communication networks that connect users and devices, including 4G, 5G, and Wi-Fi. This layer ensures that data collected from mobile devices and GPS tracking systems are transmitted quickly and reliably to the cloud and other users. It supports real-time communication, allowing instant messaging, push notifications, and live updates about livestock movements and theft incidents. Robust communication infrastructure is vital for maintaining continuous connectivity and enabling efficient data sharing within the system.

The most important component in Part A (centralised architecture) is the Crowd Processing Layer. This layer captures essential data that forms the basis for tracking and analysing livestock movements, helping to detect and respond to theft incidents promptly. Accurate and real-time data collection is crucial for the effectiveness of the tracking system. This layer receives and stores information about the livestock in question, then distributes this information to the relevant crowdsourced participants and other livestock stakeholders. To manage all these tasks, this layer consists of task manager algorithm, crowd context database, data processing algorithm, and security and privacy algorithm. On the one hand, the task manager algorithm is responsible for handling the incoming submissions of tasks from crowdsourced participants. On the other hand, the algorithm organises the distribution of tasks to the crowdsourced participants, and other relevant livestock stakeholders. The data processing element is responsible for data integration and aggregation. For example, the SAPS`s STUs may want to discover the location to which most leads, hints or tips about specific stolen livestock.

The privacy and security 'manager' component are responsible for three aspects: compliance with POPIA Act of South Africa; data security; and access control and authentication. Cybersecurity methods such as encryption, tokenization, anonymization and pseudonymization can be enforced in the privacy and security manager to keep the details of the crowd anonymous when broadcasting information on the frontend of the application. Data encryption refers to a security method that translates data into a code, or ciphertext, that can only be read by people with access to a secret key or password (CLOUDIAN, 2024). Anonymization refers to a method that replaces original clear data with a value that is both unrelatable to the original data and permanently irretrievable. Pseudonymization refers to taking identifiable data and replaces it with a value that cannot be linked to a specific individual without additional information that can be accessed elsewhere (Prime Factors, 2024).

In the centralised architecture, mobile crowdsourcing tasks would generate a large volume of data, as this data would be gathered from a large number of crowdsourced participants over a period of time. Therefore, there is a need for a robust and scalable database structure that can effectively manage and store the large volumes of data collected from various crowdsourced participants without compromising the integrity of the data. For this purpose, context database refers to the cloud storage. All the crowdsourced information collected by mobile devices would be recorded and analysed in the cloud-based database storage. Crowd Processing Layer would provide the infrastructure for storing and processing the vast amounts of data collected by the system. Cloud computing platforms, such as AWS, Google Cloud, Microsoft Azure, and SITA`s cloud environment can offer scalable storage solutions and powerful data processing capabilities. This layer ensures that data is securely stored and easily accessible for analysis and reporting. It supports the real-time processing of data, enabling quick responses to theft incidents and efficient management of livestock tracking information. Cloud infrastructure is essential for handling the high volume of data and ensuring the system's reliability and scalability.

Part B refers to a decentralised architecture. In contrast, in the decentralised architecture, all information exchange and communication occur among crowdsourced mobile users, without the information going through the Crowd Processing Layer. In this way, each mobile device is able to process and distribute its information to other mobile devices in the crowd without relying on any centralised authority. Each mobile user is able to communicate and exchange information about stolen/lost/missing/stray livestock with other users in the local vicinity.

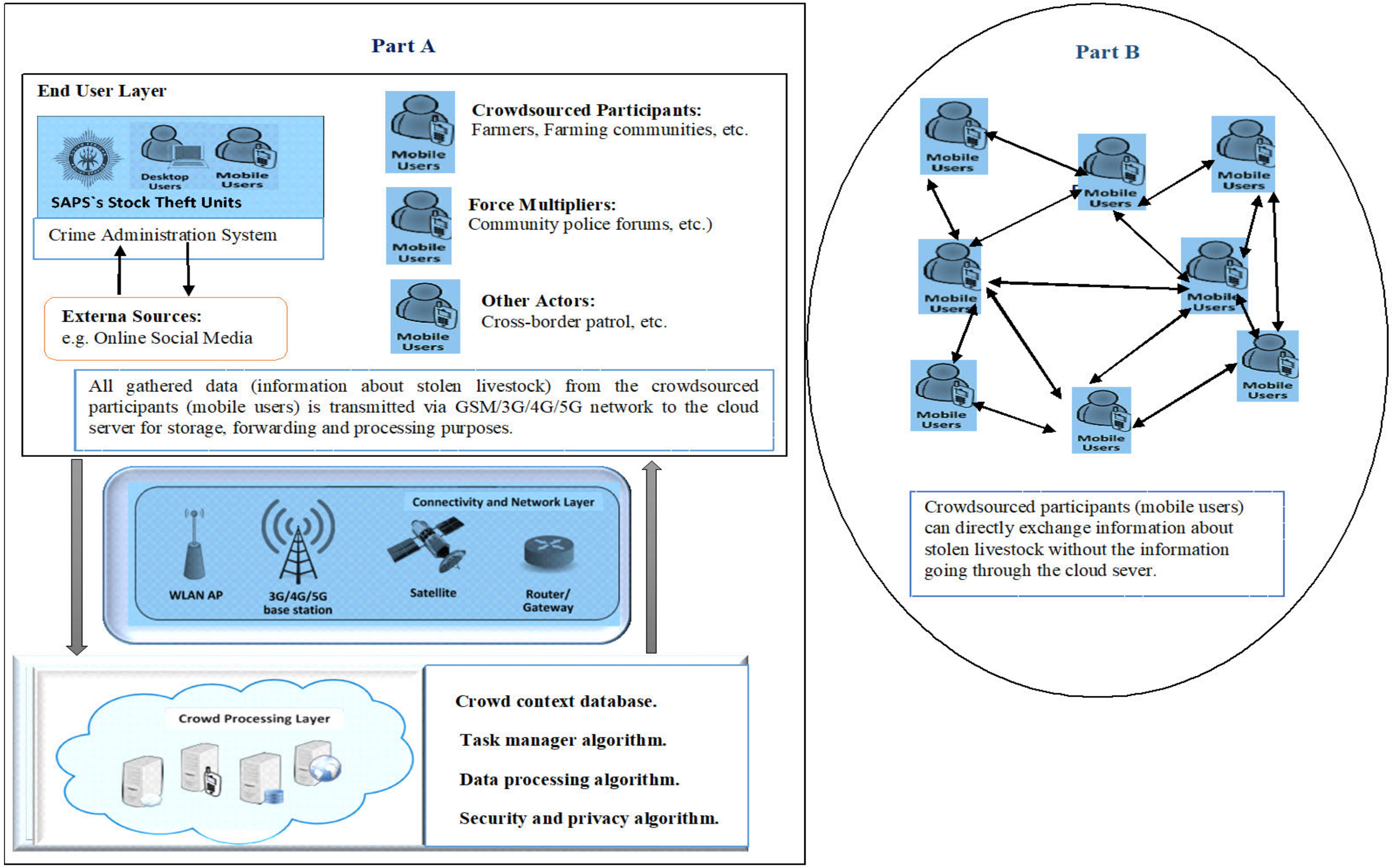


Figure 34: Proposed mobile crowdsourcing approach
Source: Author`s own illustration based upon evidence collected and applied.

How should the mobile crowdsourcing system be implemented?

The SAPS`s core businesses are to prevent, combat/control and investigate livestock theft, while the National Intelligence`s core businesses are to provide timely, insightful, objective, and relevant intelligence about livestock theft. The Stock Theft Preventative Forums` core business is to control stock theft. In this regard, the governance and oversight of the proposed national and coordinated mobile crowdsourcing system should be the responsibility of the three structures: SAPS, National Intelligence and National Stock Theft Preventative Forum. These three institutions can be regarded as the 'crowdsourcer' for the proposed national and coordinated mobile crowdsourcing system. Since the core business of the three institutions is not ICT, they may not have the technical capacity to manage and implement the national and coordinated mobile crowdsourcing system. Institutions such SITA and CSIR can be approached to partner with SAPS and assist SAPS with the technical implementation of the proposed national and coordinated mobile crowdsourcing system for controlling livestock.

8.5.2.2. Drone Use Integrated with Cloud Services and Remote-Activated and Camera Traps Integrated with Cloud Services

This section focuses on two basic questions. First, "why use drones and camera traps for tracking stolen livestock in the country?" Second, "what are the components of the proposed use of drones and remote-activated and camera traps with each integrated with cloud services?".

Why use drones and remote-activated camera traps?

In chapter five on the subject of livestock identification and tracking methods in South African context, the researcher found that attaching GPS tracker devices and RFID devices on animals would be a very expensive exercise. This is due to the nature and dynamics of the livestock sector in the country. GPS tracker devices and RFID tags do not offer a permanent solution as they can be easily removed by thieves. Attaching devices on animals that are removable by thieves does not provide a value proposition for investment. Instead it leads to depletion of funds and incurrence of unnecessary costs. Furthermore, three issues against RFID microchips emerged from the empirical findings and literature review: religious beliefs; animal welfare; and contamination of meat. These devices are impractical in the communal livestock sectors where livestock wander around in large grazing areas. Similarly, attaching IoT devices on every livestock and deploying IoT gateways would be logically impractical and a very expensive exercise for the South African rural based livestock farming sector.

The most feasible technologies suitable for the South African context would be drones and camera traps. This is supported by the findings from the primary data. The findings revealed that livestock hotspot areas in the country are not easily accessible by transportation due to unfavourable, forested, and mountainous terrains. The use of drones would enable tracking of livestock in the accessible terrains. The findings from the primary data revealed that one of the tracking methods used by the police and farming communities is stock raids. Other identified livestock tracking techniques include road blocks by SAPS, and random searching by SAPS and farmers for stolen livestock in the animal pounds. These methods are expensive as government resources such as vans, trucks, police dogs and a large number of human resources (law enforcement officers, etc) have to be utilised for these exercises. The use of drones would mitigate stock raids and random searching for livestock at animal pounds. The literature review suggests using technology such as drones to patrol inaccessible areas and livestock theft hotspots more effectively. Camera traps and the use of drones would also enable cross-border tracking of livestock theft. Based upon this evidence from primary and secondary data that drone use and camera traps are proposed for tracking stolen livestock.

In the context of this research study, camera traps refer to concealable and small devices, ranging in size from a shoe-box to a GPS car navigation unit (or even smaller), generally used to capture images or videos of the presence of objects. Camera traps can be programmed to detect the presence of any object. However, in the context of the study the object could be cattle, sheep or goats. Camera traps can be very useful in accessible or 'unfriendly' terrains as they offer an opportunity to capture new forms of data that may be difficult or impractical to collect (Sajun & Zualkernan, 2022). Imtihan et al. (2021) implemented a similar model in Indonesia, wherein IoT devices for image capturing were placed at strategic locations to detect livestock thefts and then alert the District Police.

Due to the nonexistence of Wi-Fi based stations and IoT gateways in the rural areas in the country, the proposed camera traps should be cellular based and leverage the GSM network (3G, 4G, 5G, etc.). Where there is no GSM network coverage, the camera traps can be configured to transfer data via satellite connectivity. They should be embedded with GPS sensors to transmit their location along with the detected visuals to the cloud server. The camera traps should be placed at the inaccessible livestock theft hotspots and around the national border areas where livestock thefts are prevalent. They can also be placed at strategic locations where livestock theft is likely to be prevalent in the future.

The results of data collected by agricultural drones can contribute to big data, data analytics and machine learning. Agricultural drones have limited capacity when it comes to heavy computations such as big data, data analytics and artificial intelligence. Agricultural drones typically have processor (CPU) constraints, limited battery capacity and computing power, and insufficient memory. This limits drones from storing large datasets and executing complex computational tasks (Hassanalian & Abdelkefi, 2017). Cloud computing is a technology paradigm that can overcome these drone technical limitations. There are several benefits from integrating drones with cloud services, including computation offloading from drones, provision of storage and computation services by the cloud, and virtualising drone resources through abstract interfaces (Koubâa et al., 2017). Integrating drones with cloud services allows intensive computing such as big data and analytics to be performed on the cloud severs, rather than by drones. Therefore, evidence leads to drone use integrated with cloud services as one of the solutions for tracking stolen livestock theft, as a strategy to control livestock theft in the country.

Just like the drones, the results of data collected by camera traps can contribute to big data and analytics, artificial intelligence, and machine learning. By nature, camera traps are not designed to store large amounts of data or perform complex computation tasks. This is due to their limited memory and storage capacity together with processor constraints. The key role of a camera trap is to detect and capture images of suspicious livestock theft. If rich knowledge is to be derived from camera traps, there is a need to integrate them with cloud services. The integration approach would enable collation and storage of large datasets, automated analysis of large datasets, and automated alerts potential livestock theft activities to the relevant authorities, institutions, structures or stakeholders. Hence, evidence leads to camera traps integrated with cloud services as one of the strategic solutions to control livestock theft in the country.

<u>Of what components should the drone use integrated with cloud services and remote-activated and camera traps integrated with cloud services consist?</u>

The technical architecture of the proposed drone use integrated with cloud services is illustrated in the figure 35 below.

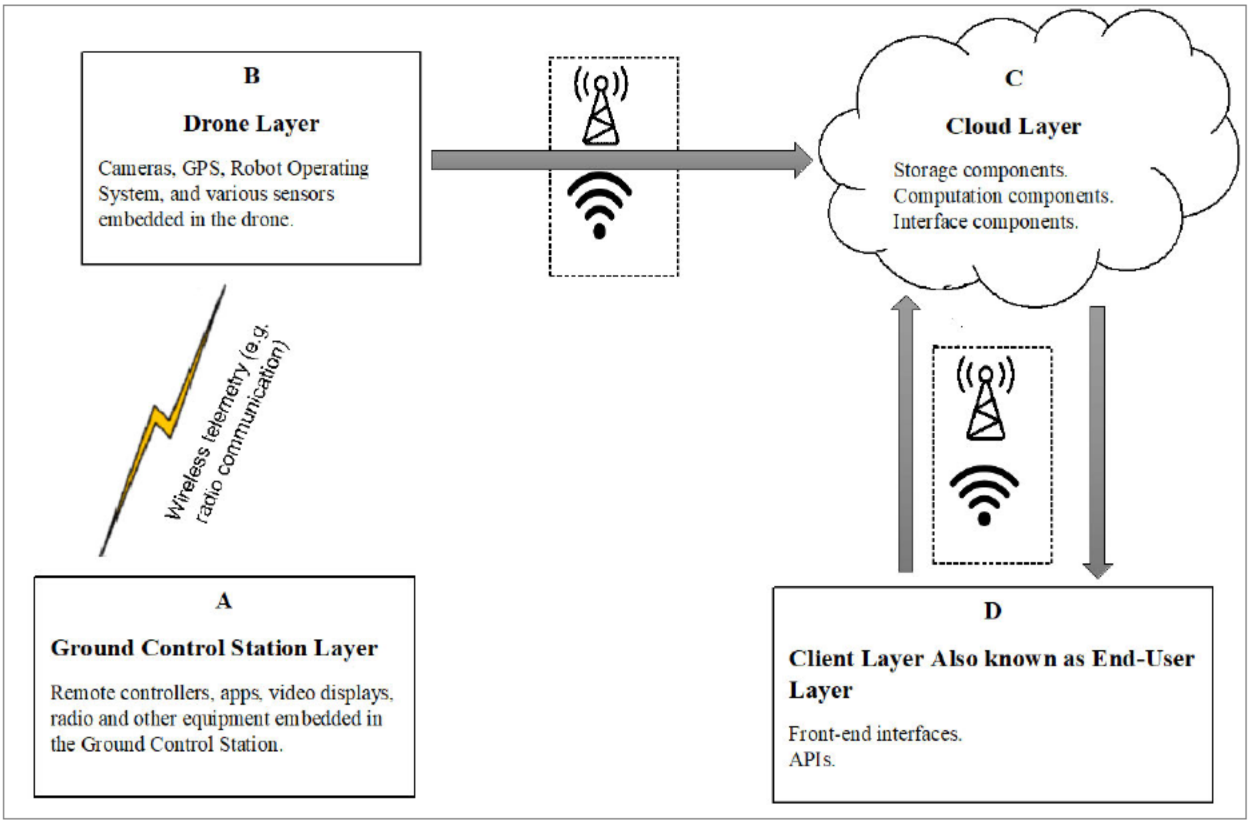


Figure 35: Architectural components for the proposed drone use integrated with cloud services
Source: Author`s own illustration

As illustrated in figure 47 above, the technical architecture consists of the following layers:

(a) Ground Control Station Layer (Part A): This layer is made up several technical components and drone operators. The main purpose of this layer is to direct the drone.

(b) Wireless communications component: Data transfer between drones and ground control station devices can be accomplished through radio technology communication. Satellite and GSM communication between the drone and ground control station devices is also possible.

(c) Drone Layer (Part B): This layer consists of hardware components, embedded sensors, accessories and software that make up the drone. For the drone to send the captured images into the cloud store, it has to connect to a wireless network such as GSM, satellite or WiFi.

(d) Cloud Services Layer (Part C): The storage and real-time processing of incoming drone data can be performed in the cloud server.

(e) User Layer also known as Client (Part D): User can have access to the process and analysed drone data to derive insights, patterns, implications about livestock theft, and then make informed decisions.

The technical architecture of the proposed camera traps integrated with cloud services is illustrated in figure 36 below.

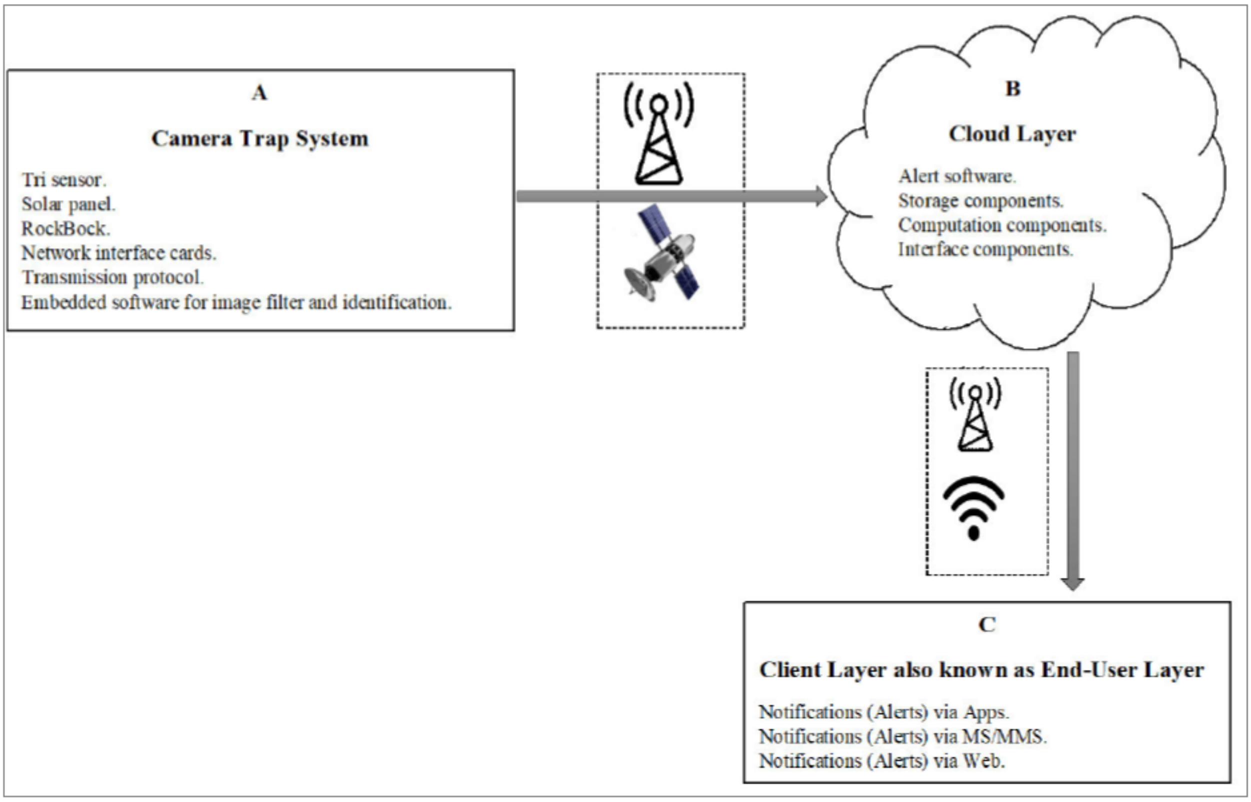


Figure 36: Architectural components for the proposed camera traps integrated with cloud services.
Source: Author`s own illustration

As illustrated in figure 29 above, the technical architecture consists of the following layers:

(a) Camera Trap System (Part A): This is the most important layer in the overall architecture, because this is where image detection, filtering and identification pertaining to suspicious livestock theft activities takes place.

(b) Wireless communications component: Data transfer from the camera traps into the cloud server can be accomplished through wireless technologies such as satellite and GSM.

(c) Cloud Services Layer (Part B): The storage and real-time processing of incoming data from camera traps is performed in the cloud server. The cloud is responsible for forwarding alerts about detected images of suspicious livestock theft to the relevant and authorised stakeholders.

(d) User Layer (Part C): In this layer, the relevant and authorised stakeholders can view alerts about detected images of suspicious livestock theft using their mobile devices or computers.

As already established in chapter five, drones can be embedded with various sensors to strengthen livestock tracking. For the proposed use of use drones in the South African context, the recommended drone sensors and features/functionalities are described in table 35 below.

Table 35: Embedded sensors for the proposed drone use

Sensors/Features	**Embed the Sensor/Feature?**	**Functionalities**	**Value Propositions**
Wireless connection capability.	Yes.	Where there is access to wireless network such as Wi-Fi, drones should leverage on such technologies for data transfer.	To enable faster transfer of drone data into the cloud server.
User-friendly Interface.	Yes.	The drone interface should be easy to navigate. It should be configured to be similar to a smartphone interface or Windows interface.	To enable easy and quick adoption of drones by the members of SAP`s STUs.
GPS module.	Yes.	GPS is the most common GNSS in South Africa. Drone use should incorporate GPS in order to guide the drone to fly to the proper direction.	Smarter, efficient and effective us of drones.
Long battery lifespan.	Yes.	The drone battery should withstand longer hours. The battery warranty should be in accordance with international standards.	To reduce accidents that may be caused by drone from falling due to battery failure.
LiDAR.	Yes.	The drone should be able to scan livestock from a distance and provide data of high-resolution.	To cover larger square kilometres in flight with accuracy when tracking livestock.
Multispectral.	Yes.	For high precision image and video capture.	For better insight when tracking livestock.
Thermal Infrared (TIR).	Yes.	Night vision capabilities, etc.	To be able to track livestock in the absence of light, and in the presence of obscurant such as fog and mist.
Bluetooth module.	Yes.	There may be instances when drone data needs to be transferred to PCs or mobile devices.	To enable data transfer from drones to other devices such as PCs or smartphones.
USB Module.	Yes.	There may be instances when drone data needs to be transferred to PCs or mobile devices.	To enable data transfer from drones to other devices such as PCs or smartphones.
GSM (3G, 4G, 5G, etc.) module.	Yes.	Where there is no access to Wi-Fi, drones should leverage on such technologies for data transfer.	To enable the transfer of drone data into the cloud server, in the event of Wi-Fi unavailability or IoT gateway unavailability.
Drone App.	Yes.	For drone configuration. For drone interface for the end-user. For the drone to interface with the cloud sever.	To enable direct and automatic recording of drone data into the cloud server.
Collision avoidance sensors.	Yes.	For autonomous operations of drones.	To reduce drone accidents.

Source: Author’s own illustration

How should drone use integrated with cloud services be implemented?

The SAPS`s STUs should partner with companies such as DRONE WORLD, Fourth Industrial Revolution Incubation (‘4IRI’), South African Civil Aviation Authority (SACAA), and Drone Clouds to manage the use of drones for controlling livestock theft in the country. DRONE WORLD is the largest drone technology provider in Africa, while ‘4IRI’ provides drone technology training. The SACAA formulates drone laws and regulations in South Africa. Drone Clouds provides drone-based cloud services (storage and analytics).

The suggestion about trained and qualified members of STUs from SAPS to operate drones is informed by the obtained findings. The findings from the literature revealed that drones are still inaccessible among livestock farmers due to high costs of drones, inadequate related knowledge and application of the use of drones, and lack of capacity and resources (drones). Numerous drone legislative requirements including licensing of operators set out by the Civil Aviation Act hinders the use of drone among livestock farmers. No use of or adoption of drones among communal farmers was obtained from primary data and literature, even though communal farmers make up the majority in the country. It is because of these drone challenges among the farmers, that, the author proposes that drones should only be operated and used by the trained and qualified members of STUs from SAPS for the purposes of tracking stolen livestock.

8.5.3. Proposed Solution for Knowledge Management and Knowledge Dissemination on Livestock Theft

Having identified the research gaps in the literature and empirical data, the researcher suggests the following ICT-based approaches of knowledge management and knowledge dissemination on livestock theft:

- **Cloud-based server, centralised and cloud-based portal:** Information related to livestock identification methods, tips on preventing livestock theft, technologies for mitigating livestock theft, and livestock trends in the country is still fragmented. All the information related to livestock theft in the country should be classified/categorised according to specific aspects/topics and stored in a cloud-based server for easy accessibility with any device (mobile, computers, etc.). The existing national and provincial Stock Theft Preventative Forums in partnership with other structures such as SAPS, farming community forums, and the DALRRD should be the custodians of the portal. The content should be simplified and made available in all the South African languages. The SITA can be approached to assist with technical implementation in this regard.

- **Leveraging the proposed mobile crowdsourcing system**: The information related livestock theft stored in cloud-based server should be disseminated through mobile devices to the farmers and farming communities. In this case, social media and instant messaging can play a big role, since the use of cloud based mobile application such as WhatsApp is common in the country. The SITA can be approached to assist with technical implementation in this regard.
- **Radio and TV for knowledge dissemination:** Information related livestock theft should be disseminated through radio and TV for the benefit of rural farmers and farming communities.
- **E-workshops, e-seminars and postdating:** Commercial farmers are already at the advance stage in term of technology acquisition. Information related livestock theft can be disseminated through advanced virtual platforms. This would benefit commercial farmers.
- **Leveraging the Agricultural Extension Officers (AEOs):** The AEOs should work closely with the farmers on the 'ground'. It is suggested that they should use their working relationship with farmers to disseminate information related to livestock theft, and also educate livestock farmers about livestock identification, and livestock theft control and prevention.

8.6. Communication

This activity of DSRM describes the ways in which the researchers will communicate the problem and its importance, the findings to the research communities, practice communities, and concerned communities (Petters et al., 2007). According Petters et al. (2007), communication efforts have to be directed to the academic (academic journals and conferences), professional communities (presentations to professional audiences) and the affected communities. The researcher will implement the following:

- A copy of the thesis with the research study`s findings and the proposed model will be sent to SAPS`s national office, as requested by SAPS.
- The findings of the research study and proposed model will be shared with the Stock Theft Preventative Forums, and representatives of livestock farming organizations.
- An electronic version of the thesis document will be made available online through UKZN library.
- Publications in the form journal articles will be explored.
- Conference presentations will also be explored.

8.7. Business Case for the Proposed Conceptual Model

8.7.1. Introduction

In this section, the researcher develops a business case for the proposed solution. The proposed solution is a model of a livestock identification and tracking system for controlling livestock theft in South Africa. Sheen and Gallo (2015), and Harvard Business Review (2010) define a business case as a tool for identifying and comparing multiple options for pursuing an opportunity and then proposing the one option that will create most value. Hillson and Simon (2020) further adds that a business case provides justification for undertaking a project, system, programme or portfolio through the evaluation of the benefit, costs and risks of alternative options and then provides a rationale for the preferred solution. These definitions are in line with the definition provided by Government of Canada (2009). There are several phases involved in developing a business case. The phases include, but are not limited to, identifying the business problem, identifying the alternative solutions, recommending a preferred solution, and describing the implementation approach (Government of Canada, 2009; Sheen and Gallo, 2015; Business Review, 2010).

The development of the business case is supported by the findings from the primary collected data (as established in chapter 7), proposed model (solution) as established in chapter 8, secondary data and literature analysis (as established in chapters 3, 4, and 5), and background information (as established in chapter 1). The researcher relied upon a business case model to guide and develop the business case for the proposed ICT-based solution to control livestock theft in the county. The business case model enabled the researcher to describe the strategic context, provide an analysis of the viable options and alternative ICT options.

This section is organised as follows: sub-section 8.7.1 provides an overview of this section. This is followed by sub-section 8.7.2, which provides a description and an illustration of the adapted business case model. This is followed by sub-section 8.7.3 in which the strategic context of the business case is described. The most important sub-section is 8.7.4, in which the associated costs, risks, benefits, community expectations and institutional capacity are analysed.

8.7.2. Adapted Business Case Model

Hillson and Simon (2020), Sheen and Gallo (2015) and Harvard Business Review (2010) proposed a basic business case model; while Government of Canada (2009) proposed a comprehensive business case model. To develop the business case for the proposed solution the researcher has adapted the comprehensive business case model provided by Government of Canada (2009) to the South African context. This business case model was adapted because of its supporting policies, tools, frameworks, templates and practical examples. It is shown in figure 37 below.

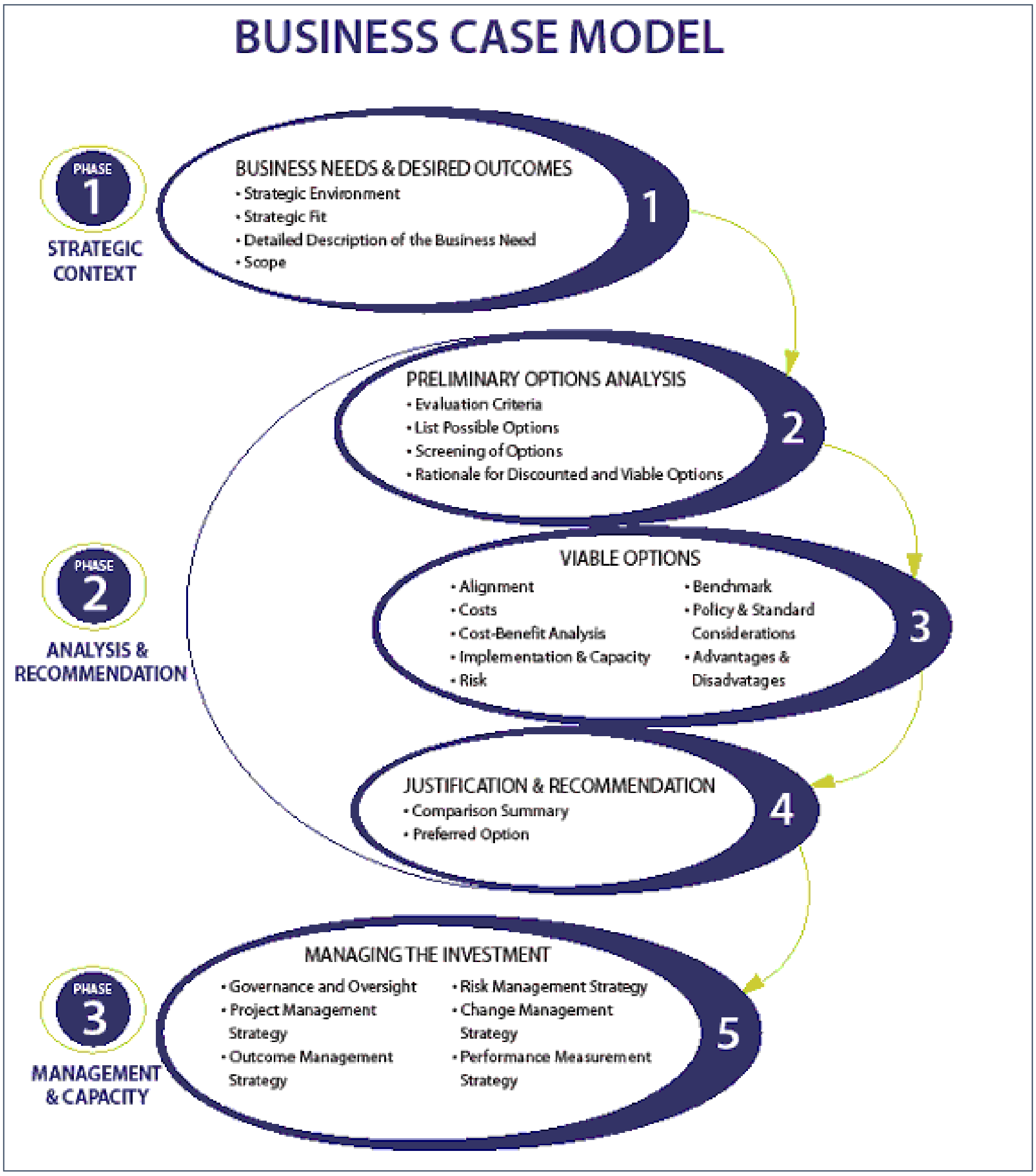


Figure 37: Business case model adapted for the research study`s business case
Source: Government of Canada (2009)

8.7.3. Strategic Context

As earlier indicated, this sub-section focuses on describing the strategic environment, strategic fit, business need, and scope. In this regard, the purpose of the sub-section is to establish the case for change and clearly define the need for the ICT-based solution (Government of Canada, 2009).

The business case model adapted from Government of Canada (2009) poses six basic questions as shown and explained in table 36 below

Table 36: Basic questions for the strategic context

Basic question	**Explanation of the basic question**
1. Where are we now?	Description of the current business environment (Government of Canada, 2009).
2. Where do we want to be?	Description of the business objectives (Government of Canada, 2009).
3. What is the business need?	Description of the problem or opportunity facing the society or organisation and the associated proposed solution (Government of Canada, 2009).
4. What has triggered the need for change?	Description of the drivers for change. The drivers for change could be aspects such as efficiency, effectiveness, policy, demographics, politics, economics, society, ICTs, law, ecological, etc. (Government of Canada, 2009).
5. What are we trying to achieve?	Description of the desired business outcomes (Government of Canada, 2009).
6. What is a strategic fit?	Description of how the proposed ICT solution maps to the institutional and government goals, priorities, outcomes, policies, and frameworks.

Source: Author`s own illustration

In table 37 below, the six basic questions described in the table above are addressed in the context of livestock identification and tracking system for controlling livestock theft in South Africa.

Table 37: Addressing the strategic context basic questions

Basic question	**Addressing the basic question in context of the livestock identification and tracking system for controlling livestock theft in South Africa**
1. Where are we now?	The South African livestock farming communities, police and relevant stakeholders mostly rely on conventional approaches when identifying and tracking stolen livestock.
2. Where do we want to be?	The objective is to analyse the costs, risks, benefits for livestock identification and tracking to control livestock theft.
3. What is the business need?	Livestock theft is a national problem in South Africa, affecting farmers, the agricultural economy, and rural communities. This criminal activity not only results in financial losses but also threatens food security and disrupts the livelihoods of farmers. To overcome the limitations of conventional livestock identification and tracking methods, this business case examines ICTs as strategic tools for controlling livestock theft.
4. What has triggered the need for change?	The current conventional livestock identification approaches and livestock tracking approaches do not meet the sophisticated, organised and cross-border dynamics of livestock theft in the country.
5. What are we trying to achieve?	The business outcome is to illustrate and describe a cost-effective and low risk ICT solution for controlling livestock theft that can offer better

Basic question	Addressing the basic question in context of the livestock identification and tracking system for controlling livestock theft in South Africa
	benefits and 'value' to the farming communities, government and other relevant stakeholders.
6. What is a strategic fit?	In the National Rural Strategy document, there is an emphasis on an integrated and multidisciplinary approach, including the mobilisation of the rural communities to control livestock theft in the country (Visible Policing, 2019).

Source: Author`s own illustration

8.7.4. Analysis and Recommendation

This sub-section is considered the 'heart' or cornerstone of the business case (Government of Canada, 2009). The first objective of this sub-section is to examine the needs of the community expectations against the institutional (police, government, etc.) capability to provide the necessary support. The second objective is to analyse the costs, risks, benefits for the livestock identification and tracking to control livestock theft. The outcome is to illustrate and describe a cost-effective and low risk ICT-based solutions for controlling livestock theft that can offer better benefits and 'value' to the farming communities, government and other relevant stakeholders

8.7.4.1. Community Expectations against the Institutional Capacity

The sub-section focuses on the analysis of community expectations against the institutional (police, government, etc.) capacity to provide the necessary support. The objective is analyse the institutional position and see how it matches the community expectations. To illustrate the analysis of community expectations against the institutional capacity; the researcher has created table 38 below. In the context of this section, the term 'community expectations' refers to the various types/categories of 'actor-network' that could be formed by the actors for common agendas. These emanated from the gathered and analysed in chapters 3, 4, 5 and 7. Some examples include livestock monitoring through drones and mounted cameras, livestock location tracking through GPS tracker devices, big data analytics through cloud computing, alerts (notifications) through mobile devices, connected livestock society through IoT, local cattle identification system. The analysis shows that there is a mismatch between community expectations and the institutional (police, and government) capacity regarding 'livestock location tracking through GPS tracker devices', and 'connected livestock society through IoT'.

All other community expectations match with police capacity or other institutional capacity. For instance, the SAPS`s mission on drone-based surveillance capability, information gathering and analysis is ‘inline’ with the proposed solution on drone use integrated with cloud services. The SAPS`s mission on community outreach through radio stations is ‘inline’ with the proposed solution for knowledge management and knowledge dissemination on livestock theft. The SAPS`s mission on integrated and multidisciplinary approach towards combating livestock theft is ‘inline’ with the proposed crowdsourcing system. In terms of capacity, the SAPS has existing Crime Intelligence Units, Visible Policing Mounted Units, Corporate Communication Unit, Technology Management Services Division, and STUs (SAPS, 2023; Visible Policing, 2019). The SAPS`s outsourcing of ICT infrastructure and technical engineers from SITA is ‘inline’ with implementation approaches described earlier in section 8.5 for the proposed solution. The Department Rural Development and Land Reform (DARDLR) has various extension offers, animal technicians and animal production specialists that are spread across the county. The DARDLR`s capacity is ‘inline’ with the proposed biometric solution for capturing and recording the animal`s retinal patterns. The SITA`s mission on positioning itself as the national cloud service provider for the South African government through a focused cloud programme is ‘inline’ with implementation approaches described in section 8.5 for the proposed solution.

Table 38: Community expectations against the institutional capacity

Community expectations	**Police (SAPS) capacity**	**Other institutional capacity**	**Match or Mismatch?**
Livestock monitoring through drones and mounted cameras [Source: chapter 7, section 7.3.5].	"Building an effective short term, medium term and long-term capacity (human & physical) for rural technology capacity such as IT system-based reporting, drone-based surveillance capability, information gathering and analysis". Existing units such as Crime Intelligence, Visible Policing Mounted Units, STUs, etc. (SAPS, 2023; Visible Policing, 2019).	------------------	Match.
Livestock location tracking through GPS tracker devices [Source: chapter 7, section 7.3.5].	No short term, medium term or long-term capacity plans for GPS tracker devices for livestock tracking.	No short term, medium term or long-term capacity plans for GPS tracker devices for livestock tracking from Department Rural Development and Land Reform (DARD&LR)	Mismatch.
Big data analytics through cloud computing [Source: chapter 7, section 7.3.5].	No short term, medium term or long-term capacity plans for advanced 4IR technologies such as AI, machine learning, robots, etc.	SITA has cloud database hosting capabilities. SITA is positioning itself as the national cloud service provider for the South African government through a focused cloud programme (SITA, 2017b).	Match.
Alerts (notifications) through mobile devices [Source: chapter 7, section 7.3.5].	Members of SAPS have adopted mobile phones.	Members of many government departments have already adopted mobile phones.	Match.
Connected livestock society through IoT [Source: chapter 7, section 7.3.5].	No short term, medium term or long-term capacity plans for IoT.	No short term, medium term or long-term capacity plans for IoT by the Department Rural Development and Land Reform (DARDLR) in the context of livestock farming sector.	Mismatch.
Local cattle identification system [Source: chapter 8, section 7.3.5]. Low-cost national livestock system. [Source: chapter 7, section 7.3.5].	------------------	The Department Rural Development and Land Reform (DARDLR) has various extension offers, etc.	Match.
Business intelligence functionality/feature [Source: chapter 7, section 7.3.5].	"Building an effective short term, medium term and long-term capacity (human & physical) for adequate policing intelligence, information, data and data processing systems, including computer applications, information systems, data and information content, timeliness, presentation, format, reliability and validity, data correlation and fusion" (SAPS, 2023; Visible Policing, 2019).	------------------	Match.

Community expectations	Police (SAPS) capacity	Other institutional capacity	Match or Mismatch?
Social media networks [Source: chapter 7, section 7.3.5].	SAPS has existing social media pages.	Other stakeholders have adopted social media applications.	Match.
Online community forums [Source: chapter 7, section 7.3.5].	Rural safety officers who are part of rural forums. Traditional Policing Concept has been implemented in various provinces.	------------------	Match.
Collaborative livestock theft reporting system. Reporting system functionality - reporting of livestock theft [Source: chapter 7, section 7.3.5].	"Building an effective short term, medium term and long-term capacity (human & physical) for rural technology capacity such as IT system-based reporting, drone-based surveillance capability, information gathering and analysis". Existing units such as Crime Intelligence, STUs, etc. (SAPS, 2023; Visible Policing, 2019).	------------------	Match.
Radio broadcasting for livestock theft information dissemination [Source: chapter 7, section 7.3.5].	SAPS has a Corporate Communication unit. The unit deals with community outreach through radio stations. The SAPS`s community outreach through radio are aimed maximising safety education by sharing safety tips through the on-air radio Crime talk slots to create a safer environment in the communities. The programmes are also aiming to strengthen strong partnership between the police and the media in the fight against crime (SAPS, 2017).	National Stock Theft Prevention Forum and Provincial Stock Theft Presentation Forum exist. Red Meat Organisations exist.	Match.
Livestock population register though computerised database. Livestock verification system [Source: chapter 7, section 7.3.5].	SAPS have access to National Forensic DNA Database (NFDD) and AIS. Outsourcing of ICT infrastructure and technical engineers from SITA. Existing SAP`s Technology Management Services Division (SAPS, 2023).	SITA has cloud database hosting capabilities. SITA is positioning itself as the national cloud service provider for the South African government through a focused cloud programme (SITA, 2017b). AIS exists, but the system is obsolete. The system does cater for individual and unique identification of animals. The National Forensic DNA Database is not suitable for routine livestock identification.	Match. There is need for a complete overhaul of existing databases. The existing databases are not designed for individual and unique identification animals.

Source: Author's own illustration

8.7.4.2. Risks, Costs, Benefits, Strengths and Weaknesses

The researcher has created two matrix tables (tables 39 and 40 shown below) to aid the analysis of the alternative and viable options for addressing the business need. The analysis begins with the alternative options, as shown in table 39. Table 40 shows that the alternative options such as GPS tracker device ‘carry’ high costs. For instance, implementing GPS tracker devices would cost the country more than R50 billion if all livestock (cattle, sheep, goats) are taken into consideration. The R50 billion cost is based on attaching GPS tracker devices to animals; and this excludes other costs such as logistics, maintenance, software packages, recycling, etc. The RFID tags would cost the country more than R350 million if all livestock (cattle, sheep, goats) are taken into consideration. The RIFD bolus and RIFD implants would cost the country more than R3 billion if all livestock (cattle, sheep, goats) are taken into consideration. These costs exclude setup and installation, RFID readers, deployment, tag applicators, and human resources.

In addition to high costs, there are many risks associated with GPS tracker devices. For instance, there is a high risk of being tampered with by livestock theft perpetrators. Another risk has to do with cross-border theft of livestock. The RFID numbering system would only be unique in the country, but not necessarily unique internationally – this does not resolve the cases of cross-border theft and international livestock theft crime. Animal welfare is also a major concern. The table shows that there are many risks associated with RFID (tags, bolus, and implantable transponders) and GPS tracker devices in the context of livestock theft in South Africa, hence the recommendation is to “reject” RFID and GPS tracker devices. Although satellite imagery offers low cost due to readily available images, it is not suitable for routine tracking of stolen livestock. This is because of several factors such as potential bad weather conditions, and hidden terrains that hinder image collection and analysis.

Table 39: Analysis of alterative options for addressing the business need

ALTERATIVE OPTIONS							
System Module	**System Component**	**Estimated Unit Cost**	**Other Costs (e.g. Subscription costs, etc.)**	**Estimated Total Costs**	**Risks and Weaknesses**	**Benefits and Strengths**	**Recommendation: Accept or Reject?**
Livestock identification and registration	(i) RFID ear tags. (ii) RFID readers. (iii) Tag applicators.	(i) R12 per animal (Neotronics, 2022). (ii) R920 (Neotronics, 2022). (iii) R380 (SafeTage, 2022).	Maintenance costs. Recycling costs. Logistics costs. Replacement costs. RIFD app for managing the tags. Labour costs. RFID national livestock database. Training of device operators.	(i) R12 * 30^{+} livestock population = R360 million. (ii) Assuming 2000 users of RFID readers * R920 = R1,8 million. (iii) Assuming 2000 users of Tag Applicator * R380 = R760 thousand.	High risk of being tampered with by livestock theft perpetrators - may be unreliable and easily hacked or interchanged. Require human labor for their maintenance, making them time - consuming, prone to human error and may lead to swapping tags. High risk of being removed by livestock theft perpetrators. RFID numbering system would only be unique in the country, but not necessarily unique internationally – this does not resolve the cases of cross-border theft and international livestock theft crime. Physical damage or loss is an issue. Animal welfare issues (e.g. inflammation, irritation, swelling on the animal). Risks of duplicate	Unique digital identification of an individual animal within the country.	**Reject.** Risks outweigh benefits. High costs.

ALTERATIVE OPTIONS							
System Module	**System Component**	**Estimated Unit Cost**	**Other Costs (e.g. Subscription costs, etc.)**	**Estimated Total Costs**	**Risks and Weaknesses**	**Benefits and Strengths**	**Recommendation: Accept or Reject?**
					identification number due to the possibilities of various RFID tag distribution intermediary 'middlemen' and channels.		
	(i) RIFD bolus. (ii) RFID readers (iii) Bolus guns/applicators.	(i) R25 per animal (Wuxi Fofia, 2022) (ii) R920 (Neotronics, 2022). (iii) R11000 (Wuxi Fofia, 2022)	Maintenance costs. Recycling costs. Logistics costs. Replacement costs. RIFD app managing the bolus. Labour costs. RFID national livestock database. Training of device operators.	(i) R25 * 30⁺ livestock population = R750 million (ii) Assuming 2000 users of RFID readers * R920 = R1,8 million (iii) Assuming 2000 users of Bolus gun/applicator * R11000 = R22 million.	Failed in Botswana. Very few successful use cases. Poses high danger to the animal. Poses high danger to the red meat industry supply chain – recovery of the device at slaughter may be an issue. RFID numbering system would only be unique in the country, but not necessarily unique internationally – this does not resolve the cases of cross-border theft and international livestock theft crime. Reading of bolus with a RFID may difficult and time consuming. Risks of duplicate identification number due to the possibilities of	Unique digital identification of an individual animal within the country. Relatively high retention rate – cannot be easily removed or lost.	**Reject.** Risks outweigh benefits. Costs are high.

ALTERATIVE OPTIONS							
System Module	**System Component**	**Estimated Unit Cost**	**Other Costs (e.g. Subscription costs, etc.)**	**Estimated Total Costs**	**Risks and Weaknesses**	**Benefits and Strengths**	**Recommendation: Accept or Reject?**
					various RFID tag/bolus/implant distribution intermediary 'middlemen' and channels.		
	(i) RIFD implants (implantable transponders). (ii) RFID readers. (iii) RFID microchip injectors.	(i) R100 (PetSafe, 2023) (ii) R920 (Neotronics, 2022).	Maintenance costs Recycling costs Logistics costs Replacement costs RIFD app managing the transponders. Labour costs. RFID national livestock database. Infrastructure hosts such as hosting the database in the cloud. Training of device operators.	(i) 100 * 30+ livestock population = R3 billion. (ii) Assuming 2000 users of RFID readers * R920 = R1,8 million	Very few successful use cases. Poses high danger to the animal. Poses high danger to the red meat industry supply chain. RFID numbering system would only be unique in the country, but not necessarily unique internationally – this does not resolve the cases of cross-border theft and international livestock theft crime. Risks of duplicate identification number due to the possibilities of various RFID tag/bolus/implant distribution intermediary 'middlemen' and channels.	Unique digital identification of an individual animal within the country.	**Reject.** Risks outweigh Benefits. Costs are very high.
Livestock Tracking	(i) GPS tracker device (collar or ear tag).	(i) R2200 per device (ETSE Electronics, 2024).	Maintenance costs Recycling costs Logistics costs	(i) R2200 * 30+ livestock population = R66 billion. There is an option to	High risk of being tampered with by livestock theft perpetrators. High risk of being removed	Remote locating of livestock anywhere, day and night.	**Reject.** Very high costs. Risks outweigh Benefits.

ALTERATIVE OPTIONS							
System Module	**System Component**	**Estimated Unit Cost**	**Other Costs (e.g. Subscription costs, etc.)**	**Estimated Total Costs**	**Risks and Weaknesses**	**Benefits and Strengths**	**Recommendation: Accept or Reject?**
			Replacement costs GPS app managing the GPS tracker devices. Applicator equipment. Training of device operators.	implement one GPS tracker device per group of animals.	by livestock theft perpetrators. Physical damage or loss is an issue. Lack of use cases among communal farmers. Short battery life span. GPS tracker embedded with back up batteries, solar panels, etc. poses animal welfare issues to small livestock such as sheep.		
	(i) LoRa IoT devices (collar or ear tag).	(i) R850 per device (Semetech, 2019).	Maintenance costs. Recycling costs. Logistics costs. Replacement costs. LoRa app managing the GPS tracker devices. Lora cloud database. Training of device operators.	(i) R850 * 30^{+} livestock population = R25,5 billion	High risk of being tampered with by livestock theft perpetrators. High risk of being removed by livestock theft perpetrators. Physical damage or loss is an issue. Lack of use cases among communal farmers. Short battery life span. IoT tracker embedded with back up batteries, solar panels, etc. poses animal welfare issues to small livestock such as sheep. Potential electricity loadshedding and therefore	The device is embedded with battery, solar panel, transceiver chip, GPS node, and water-proof casing.	**Reject.** Very high costs. Risks outweigh benefits.

ALTERATIVE OPTIONS							
System Module	**System Component**	**Estimated Unit Cost**	**Other Costs (e.g. Subscription costs, etc.)**	**Estimated Total Costs**	**Risks and Weaknesses**	**Benefits and Strengths**	**Recommendation: Accept or Reject?**
					unavailability of IoT network.		
	Mannered aircrafts (e.g. helicopters)	Difficult to quantify the costs.	Labour costs. High costs for implementation (e.g. fuel, etc.). Noise and carbon footprint. Maintenance costs.		Danger of flying aircrafts in potentially unsafe environments when locating livestock.		**Reject.**
	Satellite imagery	Low cost because image are readily available.			Cloud coverage hampers the image collection and analysis. Bad weather hampers the image collection and analysis. Hidden terrains such as forests and mountains hampers the image collection and analysis. Image collection process may be a long process. Labelling, classifying and analysis of images may be a long process.	Available on a national scale.	**Reject.** Not suitable for routine tracking of stolen livestock.

Source: Author's own illustration

Table 40 below shows the most viable options for addressing the business need. The most viable options are based upon the proposed solution: retinal patterns-based biometric information system, mobile crowdsourcing approach; drone use integrated with cloud services; remote-activated camera traps integrated with cloud services; and knowledge management and knowledge dissemination on livestock theft. It would cost the country between R29 million and R108 million to acquire the mobile devices needed for capturing and recording the animal`s retinal patterns into the national livestock database. This calculation is based on the estimated number of agricultural extension officers in the country. It is estimated that South Africa had about 2 492 agricultural extension officers in 2022 (Manako, 2022). As already stated in section 8.5, the country already has existing dipping facilities and animal pound facilities that can be used to immobilise large livestock such as cattle. In the communal farming sector, kraals are a common facility for restraining a group of animals such as sheep, cattle and goats. There are no major animal welfare issues and risks associated with capturing and recording the animal`s retinal patterns into the national livestock database.

It is difficult to quantify the costs of biometric acquisition software for national and large-scale projects – for retinal patterns-based biometric system. This is due to unpublished prices of software packages paired with a retinal imaging device. However, the strength of the software packages is that they can be customised to suit the local context. There are no major costs associated with cloud storage service for the proposed national livestock database. This is because SITA and CSIR have cloud computing capabilities which can be leveraged in partnership with DARDLR for the proposed national livestock database.

A drone designed for security, farming, mapping, filming, counting, monitoring and tracking purposes costs about R65 000 (Africa Drone Kings, 2024). In 2021, the country had 90 stock theft and endangered species units spread across the nine provinces, of which 29 were border units and 13 were dedicated satellite units (van Rooyen, 2021). If each stock theft unit would be assigned two drones, then the estimated total cost would be about R12 million. The price of a remote-activated camera trap was about R6000 in 2023 (CapeUniMart, 2023). It is worth noting that these estimated figures exclude training costs, licencing costs, setup and installation costs maintenance costs, logistics costs, replacement costs, and costs of additional equipment to support the cameras.

Table 40: Analysis of viable options for addressing the business need

VIABLE OPTIONS							
System Module	**System Component**	**Estimated Unit Cost**	**Other Costs (e.g. Subscription costs, etc.)**	**Estimated Total Costs**	**Risks and Weaknesses**	**Benefits and Strengths**	**Recommendation: Accept or Reject?**
Livestock identification and registration	Mobile device equipped with retinal camera for portable wide field imaging – for retinal based biometric system.	(i) R14500 (Volk, 2023) or (ii) R54000 (Jovert, 2022).	Training of device users. Logistics costs. Labour costs.	It is estimated that South Africa had about 2 492 agricultural extension officers in 2022 (Manako, 2022). (i) Assuming 2000 users of the device * R14500 = R29 million or (ii) Assuming 2000 users of the device * R54000 = R108 million.	"Animal`s safety concerns about photo-biological risk for retinal photoreceptors by flashlight" (Iqbal, 2021). The risks can be minimized through proper training of device users.	Most stakeholders have already adopted mobile technology – they already know to use mobile phones and cameras. New devices have been tested, and they exist on the market. The devices are cost effective, portable and a convenient method for retinal imaging (Iqbal, 2021). "Smartphone applications that provide options for camera setting adjustment e.g., exposure setting, light intensity adjustment, manual focus option, and zoom setting are available" (Iqbal, 2021)	**Accept.** Low risk, while providing better benefits.
	Biometric acquisition software for national and large scale projects – for retinal patterns-based biometric system.	RetCheck software paired with a retinal imaging device (Optibrand, 2022). However, no public	Training of software users. Licencing costs. Labour costs.		It may take a long time to implement the system. The risks can be mitigated by collaborating with the software vendor.	Advanced software such as RetCheck have been developed and tested, and they exist on the market (OptiBrand, 2022). Such software can be customised/adapted	**Accept.** Low risk, while providing better benefits.

VIABLE OPTIONS							
System Module	**System Component**	**Estimated Unit Cost**	**Other Costs (e.g. Subscription costs, etc.)**	**Estimated Total Costs**	**Risks and Weaknesses**	**Benefits and Strengths**	**Recommendation: Accept or Reject?**
		information about the price (charging fee) is available.				for the South African context without developing a new software from scratch. The software has advanced AI functionalities for image (retinal patterns) capture, processing, comprehension and fusion within seconds. The software can be integrated with other systems through various interfaces such as API. Software can be paired with a hand-held device – this is useful for rural areas and remote locations.	
	Cloud storage service for the national livestock database.	No major costs anticipated – SITA can host the national database on their cloud infrastructure.			Potential electricity loadshedding. The risks can be mitigated by creating a distributed database.	Cloud computing offers low cost. In South Africa, SITA and CSIR have cloud computing capabilities.	**Accept.** Secure and storage of universally unique livestock identification.
	National livestock database – integrated with the retinal patterns-based biometric system.	Difficult to quantify.	Training of software users. Setup costs. Labour costs.			Universally unique digital livestock identification. Secure livestock digital identification for source verification to	**Accept.**

VIABLE OPTIONS							
System Module	**System Component**	**Estimated Unit Cost**	**Other Costs (e.g. Subscription costs, etc.)**	**Estimated Total Costs**	**Risks and Weaknesses**	**Benefits and Strengths**	**Recommendation: Accept or Reject?**
						ensure livestock recovery, prevent fraud, and reduce livestock theft.	
	API integration	No major costs			No major risks.	Connection to or integration with external systems.	**Accept.**
	Connectivity - GSM network (Telebiometrics).	No major costs. Costs can be negotiated with network operators (MTN, Vodacom, etc.)	No major costs.	No major costs	Potential electricity loadshedding and unavailability of cellular network. To mitigate the risks, the devices can be configured to temporally store data locally, then upload data into the national database as batches when network is available.	Data transfer from remote rural areas into the national livestock database. Network coverage available on a national scale.	**Accept.** GSM network is the most feasible network in the rural areas and farming communities.
Livestock Tracking	Drone.	Drone meant for security, farming, mapping, filming, counting, monitoring and tracking purposes = R65000 (Africa Drone Kings, 2024).	Training costs Licencing costs. Maintenance costs. Recycling costs. Logistics costs. Replacement costs.	In 2021, the country had 90 stock theft and endangered species units spread across the nine provinces (van Rooyen, 2021). Assuming that each SAPS`s STUs would need at least two drones, then 90 * 2 * R65 000 = R11,7 million.	Battery life span – while flying the drone; this can be mitigated through backup batteries or solar panels embedded onto the drones. Ethics and invasion of privacy while flying the drone; this can be mitigated through proper training of drone operators.	Commercially/ industrially tested drones. Drone can be embedded with advanced sensors. Drone comes with accessories such as extra battery, USB adapters, etc. Can track livestock/trace livestock in hidden areas, mountainous terrains, forests, etc.	**Accept.** Costs are much lower compared to other livestock tracking technologies.

VIABLE OPTIONS							
System Module	**System Component**	**Estimated Unit Cost**	**Other Costs (e.g. Subscription costs, etc.)**	**Estimated Total Costs**	**Risks and Weaknesses**	**Benefits and Strengths**	**Recommendation: Accept or Reject?**
	Drone software (e.g. flight controller software).	Most drones come loaded with software.	No major costs.				**Accept.**
	Integrating drone with cloud services.	No major costs – SITA can be approached for hosting, machine learning and big data analytics.	No major costs.				**Accept.**
	Remote-activated camera trap	R6000 (Camera Traps cc, 2023)		Setup costs Installation costs Labour costs. Costs of additional equipment to support the cameras.			**Accept** Costs are much lower compared to other livestock tracking technologies.
	Integrating camera traps with cloud services	No major costs – SITA can be approached for hosting.	No major costs.				**Accept.**
	Cloud storage and analytics service	No major costs – SITA can be approached for hosting.	No major costs.				**Accept.**
Mobile Crowdsourcing for Livestock Tracking	Mobile devices for crowdsourced participants	0 (zero) costs. They already own mobile phones.	0 (zero) costs.			Most stakeholders have already adopted mobile technology – they already know to use mobile phones.	**Accept.** Mobile phones are the most feasible devices in the rural areas and farming communities due to their widespread adoption.

VIABLE OPTIONS							
System Module	**System Component**	**Estimated Unit Cost**	**Other Costs (e.g. Subscription costs, etc.)**	**Estimated Total Costs**	**Risks and Weaknesses**	**Benefits and Strengths**	**Recommendation: Accept or Reject?**
	Connectivity (GSM network)	No major costs. Costs can be negotiated with network operators (MTN, Vodacom, etc.)	No major costs	No major costs	Potential electricity loadshedding and unavailability of cellular network.		**Accept.** GSM network is the most feasible network in the rural areas and farming communities.
	End-user software interface for crowdsourced participants.	Difficult to quantify as the software interface may have to be developed from scratch to suit the South African context – e.g. culture, multiple languages, etc.	Training costs. Maintenance costs. Labour costs.		It may a long take to develop the suitable mobile app for the South African context.	Open source frameworks and cloud platforms for mobile app development exist, to lower the development cost.	**Accept.**
	Crowd processing software integrated with: Crowd context database Task manager algorithm Data processing algorithm Security and privacy algorithm.	Difficult to quantify as the Crowd processing software may have to be developed from scratch to suit the South African context.	Training costs. Maintenance costs. Labour costs.		It may a long take to develop the suitable crowd processing software for the South African context.	Open source frameworks and cloud platforms for software development exist, to lower the development cost.	**Accept.**
	Cloud storage for crowd context database	No major costs anticipated – SITA can host the national database on	Maintenance costs. Labour costs.		Potential electricity loadshedding. The risks can be mitigated by creating a distributed database.	Cloud computing offers low cost. In South Africa, SITA and CSIR have cloud computing capabilities.	**Accept.**

VIABLE OPTIONS							
System Module	**System Component**	**Estimated Unit Cost**	**Other Costs (e.g. Subscription costs, etc.)**	**Estimated Total Costs**	**Risks and Weaknesses**	**Benefits and Strengths**	**Recommendation: Accept or Reject?**
		their cloud infrastructure					
Knowledge Management and Knowledge Dissemination on Livestock Theft	Information dissemination through mobile phones.	0 (zero) costs. Crowdsourced participants already own mobile phones.	0 (zero) costs.			Most stakeholders have already adopted mobile technology – they already know to use mobile phones.	**Accept.**
	Information dissemination through radio and TV.	No major costs. Costs can be negotiated with relevant radio stations.	0 (zero) costs.			SAPS has community outreach programmes through radio and TV.	**Accept.** Cheaper means of information dissemination to the public to help with controlling livestock theft.

Source: Author's own illustration

8.7. Summary of Chapter Eight

The main purpose of this chapter was to address the goal of the research study. The goal of the research was to propose an ICT-based model (solution) for controlling livestock theft in South Africa. To propose the ICT-based livestock identification and tracking solution, the researcher drew key findings, insights and implication from the analysed primary data and secondary data, and literature analysis. To develop the proposed model, the researcher applied the principles of DSRM. The proposed ICT-based solution (model) is divided into three major modules:

(i) Livestock identification and registration: A 'retinal patterns-based biometric identification information system' is proposed. This is due to its tamper-proof safeguard against livestock theft perpetrators.

(ii) Livestock tracking: For livestock tracking, three livestock tracking approaches are proposed, namely:

(a) A national, holistic and coordinated technological (mobile) crowdsourcing system integrated with panic button;

(b) Drone use integrated with cloud services. This is due to inaccessibility (unfavourable, forested, and mountainous terrains) of some livestock hotspots (areas) in the country. Also, this is proposed to mitigate the costs of traditional livestock tracking such as stock raids costs; and

(b) Remote-activated and cellular-based camera traps integrated with cloud services. Camera traps would enable tracking the cross-border of livestock theft, and can be very useful in accessible or 'unfriendly' terrains as they offer an opportunity to capture new forms of data about livestock theft that may be difficult or impractical to collect.

(iii) Knowledge management and dissemination on livestock theft: A centralized information repository, and information dissemination via mobile devices, TV and radio is proposed.

The researcher developed a business case for the proposed ICT based solution. The next chapter revisits the overall research, summarises the research study's main contributions, provides implications and recommendations, highlights the limitations and delimitations, provides suggestions for future research studies and concludes the research study.

CHAPTER 9

CONCLUSION AND RECOMMENDATIONS

9.1. Introduction

The research study consists of nine chapters in total. Chapter one introduced the research study, in which the rationale, problem, contextual background, aim, goal, research questions and objectives were provided. In chapter two, an overview of the South African livestock farming sector was presented, in which various aspects related to the livestock farming sector, livestock stakeholders, and ICT trends and developments in South Africa were discussed. Chapter three discussed the various aspects related to livestock theft in South Africa. In chapter four, the researcher provided a global literature review on livestock identification and tracking in the context of livestock theft. Chapter five described and justified the theoretical framework underpinning the research study. In chapter six, the researcher presented the research methodology guiding the research study, in which research philosophy, design/strategy, approach, sampling, data collection methods and procedures, and data analysis methods were discussed. Chapter seven focused on the analysis of gathered data, interpretation and presentation of the findings. Chapter eight provided the proposed ICT solution (model) for controlling livestock theft. This chapter brings the thesis to a conclusion by revisiting the overall research, highlighting the key contributions of the research study, providing the implications and recommendations, discussing the limitations and delimitations, and proving suggestions for future research.

9.2. Revisiting the Overall Research

The SAPS releases crime statistics and annual reports every year. The SAPS` crime statistics and annual reports indicate that livestock theft occurs in all the provinces of South Africa. This shows that livestock theft is a national problem. Similarly, the literature reviewed indicates that livestock theft is a national problem. Although livestock theft is a global phenomenon, the research study focused on South Africa. The research study sought to address livestock theft within the South African context/situation. Cattle, sheep and goats are the most targeted animals and they comprise more than 80% of all livestock stolen in South Africa. Livestock identification and tracking of stolen livestock remains a major challenge in South Africa. This is due to the ineffectiveness of conventional livestock identification and tracking methods. To address this challenge, the research study explored ICTs as strategic solutions for controlling livestock theft.

Thus, the aim of the research study was to explore how livestock stakeholders can utilise ICTs to control theft in South Africa. The goal of the research was to propose an ICT-based solution (model) of a livestock identification and tracking system for controlling livestock in the country.

To address the aim and goal of the research study, a number of research objectives and questions were provided. Qualitative data were gathered using interviews and questionnaires from the diverse participants such as livestock farmers, police, stock theft forums, etc. Secondary data and literature analysis were also used to address the research questions and objectives. To analyse the gathered qualitative data, the researcher applied thematic analysis techniques and content analysis techniques. Various key findings, insights and implications emerged from the gathered primary data and secondary data, and literature analysis.

The key findings, insights and implications resulted to the proposed ICT solution (model) for controlling livestock in the country. For livestock identification and registration, the researcher proposed a retinal patterns-based biometric identification information system as a viable ICT solution for controlling livestock theft. For livestock tracking, the researcher proposed three viable ICT solutions for controlling livestock theft: a national, holistic and coordinated technological (mobile) crowdsourcing system integrated with panic buttons; drone use integrated with cloud services; and remote-activated and cellular-based camera traps integrated with cloud services. In addition, knowledge management and dissemination on livestock theft using cloud services, mobile devices, TV and radio has been proposed.

9.3. Summary of Key Contributions of the Research Study

9.3.1. Livestock Theft Research from an ICT and IS perspective

According to Clack (2018), research on livestock theft has not been fully explored. Clack (2018) further adds that the phenomenon is largely neglected with little attention being given to it in the media. Clack & Minnaar (2018) noted that there has been a tendency to focus on other rural crimes such as the illegal wildlife trade. Donnermeyer (2016) noted that globally, there is a bias towards research in urban areas and therefore a total neglect of rural areas and the crimes on farming communities such as livestock theft.

The researcher found that much of the contemporary research on livestock theft in South Africa has been carried from a criminological perspective, and social perspective. There are very few research studies from the perspective of ICTs and livestock theft in the South African context. Livestock theft has evoked little attention among researchers in the Information Systems field and, particularly, ICTs as a potential solution to the problem of livestock theft. The author of this study could not find any research that has developed a model of an ICT-based livestock identification and tracking system for controlling livestock theft in South Africa.

This research study attempted to address livestock theft from an ICT and IS perspective in a global context with an emphasis on South Africa as a case study. In this regard, the contribution of the research can be considered as an attempt to fill the gaps of lack of ICT and IS research on livestock in South Africa. The research study brought together aspects from various disciplines. Therefore, the research study took an interdisciplinary approach combining the disciplines of ICTs, Information Systems, Agriculture (livestock), Criminology (livestock theft), and Ethics (animal welfare). This enabled the researcher to approach the research process and the proposed solution (model) from various dimensions. In addition, this interdisciplinary approach enabled triangulation. This all strengthened the quality of research study.

9.3.2. Pragmatic Solution to a Socio-economic Societal Problem

In chapter six, the researcher justified that this research study has some elements of applied research. The justifications were supported by the fact that livestock theft is a national problem that has direct/indirect socio-economic effects to the South African society (i.e. farmers, government, communities, traditional authorities and industries). The research study has attempted to address a specific practical problem, which is livestock theft in South Africa. The research study provided a novel pragmatic and ICT-based solution by developing a model system that identifies and tracks livestock to help control livestock theft in the country. The researcher has attempted to illustrate the ICT-based model system using diagrams and tables, and in descriptive form.

9.3.3. Findings from Empirical/Primary Data

This research study contributes to the body of ICT knowledge by providing empirical findings from the gathered primary data. The findings obtained from the empirical data provided an insight into the role of ICTs in the context of livestock identification and tracking for controlling livestock theft in South Africa. The findings can help other researchers to explore or conduct similar/related research studies. International researchers can explore related research studies to ascertain whether similar findings could be obtained in their countries. Institutions and stakeholders concerned with livestock theft can use the findings obtained to explore ICT interventions for controlling livestock theft.

9.3.4. Literature Analysis and Identification of Gaps and Future Research

The research study contributed a synthesis of the literature and then provided possible implications for future research and for practice. While presenting the literature in the form of a scholarly discussion, the researcher explored and identified the research gaps in the literature. This was accomplished in the literature matrix found in chapter five where the researcher likewise applied scenarios to the South African context.

9.3.5. Business Case

The researcher developed a business case which justified the model solution to livestock theft in South Africa. An analysis of the needs of the community against the capability of the police and government to provide the necessary support were provided in the business case. The business case provided an evaluation of the benefits, risks, strengths, weaknesses and estimated costs of the main ICT options (alternative options and viable options). The business case highlighted the rationale for the viable ICT solution. The provided business case can serve as the 'starting point' for comprehensive economic analysis, business planning and implementation strategies for the ICT-based solution to addressing livestock theft in South Africa.

9.3.6. Significance

Significance of the research study defines the importance of the research study as to: who is going to benefit from it, why and how they will benefit from it. This research study will be of importance to the livestock theft stakeholders. In chapter three, livestock theft stakeholders and their interests were identified and described. The proposed solution, and the findings obtained from the gathered data can help SAPS, National Intelligence, Cross-border Patrol Structures, and DALRRD in the following ways:

- Understand the nature and dynamics of livestock theft in the country; as discussed in chapter three.
- Recognise the community needs for controlling livestock theft; as established in chapter seven.
- Comprehend various traditional approaches, methods, strategies or techniques and ICTs for controlling livestock theft; as established in chapters three, four, five and seven.
- Identify modern and advanced ICTs for controlling livestock theft; as established in chapter five.
- Use/implement the proposed solution (model) as a pilot project, and then measure its outcomes before conducting a full-scale implementation.

- Refocus their strategies, approaches and techniques/methods for dealing with livestock theft towards modern ICTs and 4IR related technologies; as discussed in chapter five.

9.4. Recommendations

Recommendation 1: Collaboration and Partnership

The implementation of livestock identification and tracking system for controlling livestock theft is a complex, costly and long process that would involve multiple 'parties', and various technologies. To implement the model, it is recommended that the Department of Agriculture, Land Reform and Rural Development (DALRRD) should collaborate with institutions such as SAPS, CSIR, SITA, ARC, NSPCA, SACAA, and Drone World. The partnership can leverage modern ICTs such as open source cloud platforms to reduce the implementation costs. The partnership should involve telecommunications companies such as TELKOM, MTN, and Vodacom to reduce the connectivity costs.

Recommendation 2: Involvement of the Farming Communities during Implementation

It is recommended that livestock farmers should be directly involved when planning, designing, developing and implementing a livestock identification and tracking system. A bottom-up approach is recommended, since livestock farmers are the core stakeholders. The proposed model can be piloted in one region before rolling out to the entire country. The pilot would enable quick evaluation of system impacts, use/adoption, and benefits/value.

Recommendation 3: Consideration of Animal Welfare

Due to animal welfare issues associated with livestock identification and tracking systems, the researcher recommends that institutions such as NSPCA should be involved when planning to implement a livestock identification and tracking system.

Recommendation 3: Consideration of International and National Standards

One of the important aspects regarding the implementation of a livestock identification and registration system is international and national standards; as established in chapter four. In this regard, it is recommended that international and national standards should be followed when implementing the proposed the livestock identification and registration system. Detailed guidelines on international standards can be obtained online from ISO, IEEE, GVC, and ICAR.

Recommendation 4: Leveraging the 5G Network in the Near Future

A reported published by ICASA (2022) showed that is a penetration of 4G network coverage in the rural areas, as established chapter two. This GSM development suggests that G5 network coverage may make it into the rural areas in the near future. There is a general consensus that 5G network will provide better benefits to the society. The researcher recommends that in the near future, once the 5G network has rolled into the rural areas, there should be an exploration of '5G network potential for livestock management and monitoring'.

9.5. Limitations of the Research Study

The first limitation has to do with the sample size. When the researcher was working on the last chapters of the research study, the researcher found that there were other important informants that could have been recruited to be part of the sample for the research study. These important informants include Community Safety Forums (CPSs), Department of Cooperative Governance and Traditional Affairs (COGTA), Houses of Traditional Leaders, Animal Pounds (Pound Keepers), NSPCA, and National Intelligence. Unfortunately, time was against the researcher at this stage, as the researcher had already analysed the gathered data, and working on the final chapters. To mitigate this shortcoming, the researcher made use of the publicly available secondary data and literature. Future research studies could gather data through interviews, questionnaires or focus groups from the identified important informants. The gathered data could provide a better understanding of their perceptions, views and insights on how livestock theft can be controlled using ICTs. The sampling of farmers and traditional authorities according to the hotspots is another possible limitation to the data inclusivity and transferability of the findings of the investigation to the whole of South Africa. To minimize these limitations, literature analysis and secondary data covered in three chapters were utilised.

The second limitation has to do with the business case. The researcher found that some prices (e.g. price of retinal based biometric software) are not public information. The researcher emailed the companies, but no response was obtained from the companies. The researcher had to rely on aggregator price estimators such as Alibaba and Amazon to get cost estimations. The researcher could not conduct advanced economic analysis and financial analysis such as Net Present Value (NPV), Present Value Ratio (PVR), Internal Rate of Return (IRR), Rate of Return (RIO), means, standard deviations, and variances in the business case. This was due to a lack of data about the institution's internal cost structures, technical asserts, capital, and human resources. The figures and supporting text used in the business case were obtained from secondary data sources.

9.6. Delimitations of the Research Study

The research study`s boundaries revolved around 'livestock theft stakeholders' – i.e. those who have interests in the 'fight against' livestock. The research study was an exploration of how livestock theft stakeholders could utilise ICTs to control livestock theft in the country. The research study did not include livestock perpetrators. It may happen that livestock theft perpetrators are utilising ICTs to steal livestock, sell the stolen livestock or dispose of the stolen livestock. Future research studies could focus on livestock perpetrators and ICTs.

The above suggestion is supported by Aiyzhy et al. (2021) when they stated that:

> "In the past few years, due to the development of the information space on the Internet, animals including stolen livestock, and livestock meat, including stolen meat, have been actively sold through communities using instant messengers, such as Viber, WhatsApp, or through social networks, with home delivery to citizens. The latter do not impose any requirements for the documentation of livestock meat; therefore, for persons engaged in the theft of farm animals, there are comfortable conditions for bringing their criminal intent to completion. Considering that criminals are resorting to the possibility of using ICTs and contemporary means of communication to sell stolen livestock products, it should be noted that ICT tools can also be a possible solution to prevent theft".

Republic of Tuva (2018) supports Aiyzhy et al. (2021), when they stated that

> "At the same time, technological advances and Information and Communications Technologies (ICTs) have expanded the toolbox of crime, providing criminals with new opportunities".

This research study focused on exploring how livestock stakeholders (those in the fight against livestock) can use ICTs to control livestock theft. Future research could focus on exploring how livestock perpetrators utilise ICTs to steal livestock, distribute stolen livestock, sell stolen livestock, dispose of stolen livestock, etc. Empirical data on this topic can be gathered from livestock theft inmates/prisoners/convicts.

In terms of PESTEL application, the scope of research was more focused on the Technological dimension. Future research cloud study livestock from a political perspective. This could be done by exploring the political willingness of the high authorities to address livestock theft through ICTs in the country. Lastly, the technical implementation of the proposed ICT solution (model) is beyond the scope of this research study, because the implementation of such proposed ICT solution has costs implications, legal implications, and ethical implications.

For instance, there would be ethical implications (e.g. animal welfare considerations) involved when experimenting or piloting the retinal patterns-based biometric system on animals. For instance, experimenting or piloting drone use with integrated with cloud services would involve several requirements such as drone training, drone licence, etc.; and this would be a long implementation process. Hence, the researcher suggested the implementation by the authorities such as SITA, SAPS and DALRRD.

9.7. Suggestions for Future Research

The following future research studies are suggested:

(f) Economic analysis and business plan of the proposed solution:

The researcher recommends a comprehensive economic analysis of the proposed solution (model), taking into consideration the internal costs, revenue, budgets, asserts, capital and human resources of the institutions such as SAPS and DALRRD. Similarly, a comprehensive business plan of the proposed solutions may be conducted.

(g) ICT research on livestock theft from the perspective of livestock theft perpetrators:

As discussed in the delimitation section, future research study could focus on exploring how livestock perpetrators utilise ICTs to steal livestock, distribute stolen livestock, sell stolen livestock, dispose of stolen livestock, etc. Primary data on this topic can be gathered from livestock theft inmates/prisoners/convicts.

(h) Exploration of the willingness to implement the proposed solution from the political and legal dimensions

There are many dimensions to explore the implementation of a proposed project solution. These dimensions include PESTEL analysis, SWOT analysis, etc. Future research could focus at the political level, to explore the political willingness among the political authorities to implement the proposed solution. Interviews with people who have political influence can be conducted. Another research could explore the legal aspects/ramifications of the proposed solution.

(i) Similar research in an African country with similar livestock theft prevalence and nature

The research study can be replicated in other African countries with similar characteristics as South Africa.

(j) Similar research in another developing country (outside of Africa) with similar livestock theft prevalence and nature

The research study can be replicated in other developing countries with similar characteristics as South Africa.

(k) The country`s institutional (Police, Military, National Intelligence) readiness to deploy/implement and adopt advanced technologies for crime prevention.

An ideal future research would be investigating the country`s institutional (e.g. Police, Military, etc) readiness to deploy, implement and adopt advanced technologies such as HunchLab; geographic prediction tools such as HunchLab; and Integrated predictive analytics tools such as IBM i2 Coplink.

9.8. Concluding Remarks

Livestock theft is one of the persistent challenges facing the livestock farming sector in South Africa. Livestock theft is prevalent in all the nine provinces of the country; cattle, sheep and goats being the main target for theft. Cross-border theft of livestock into the neighbouring countries is also common. Although the livestock problem has been researched from a criminological and social perspectives, there is very little research from the ICT and IS perspectives. This background information motivated the researcher to embark on this current research to explore how ICTs can be utilised by livestock stakeholders to control livestock theft. With this aim in mind, the goal of the research study was to propose an ICT-based solution (model) for controlling livestock theft within the South African context.

The researcher gathered both primary and secondary data when undertaking qualitative research with the former inclusive of interviews from a wide range of livestock stakeholders. The analysis of the interview data and literature enabled the researcher to gain insights into ICTs and livestock theft in the country. This in turn enabled the researcher to develop the proposed the ICT-based solution for controlling livestock theft in the country. Therefore, this research study contributes to narrowing the ICT and IS based on livestock in the South African context by proposing a practical ICT-based solution (model) that may be of assistance to the country`s institutions (SAPS, National Intelligence, Stock Theft Preventative Forum, Red Meat Organisations) and farming communities.

9.9. A Self-Reflective Journey

While writing my thesis, I learnt various aspects of the research process. I learnt how to use a combination of scoping review method, snowball strategy, PRISMA and CASP when conducting literature review. I must acknowledge that initially I struggled to organise, classify and arrange literature information into a proper structure for synthesis and report writing. Hence, I decided to group/arrange the literature synthesis by technologies and approaches, as presented in chapter four, section 4.11. The struggle was due to a lot of literature information obtained on the subjects of ‘livestock identification’, ‘livestock theft’, and ‘livestock tracking’.

I learnt that a theory may not fully cover all the concepts/constructs of the undertaken research study. The theory may need to be reconceptualised and contextualised to suit the research study`s aim, objectives and goal. One of the most important aspects is the justification of the chosen theory underpinning the research study.

I found the data collection stage to be one of the challenging aspects in the research process. This is due to various factors, including the unwillingness of participants to participate in the research study. In general, people tend to be reluctant to participate in a research study if there are no incentives/rewards in answering questionnaires or partaking in interviews or focus groups. Sometimes, participants do not understand the value of participating in a research study. The researcher had to explain the importance of the research study and how it will benefit the community/society.

The part I enjoyed the most was the analysis of data, and interpretation of findings (chapter 7), and solution (model) proposal (chapter 8). Overall, the research process was a learning experience, while enduring the challenges.

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Appendices

Appendix A: Ethical Clearance

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

2 March 2017

Mr Mpho Mzingelwa (215082567)
Graduate School of Business & Leadership
Westville Campus

Dear Mr Mzingelwa,

Protocol reference number: HSS/0109/017D
Project title: Livestock identification and tracking system: Case study of South Africa

Full Approval – Expedited Application
In response to your application received 25 January 2017, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol has been granted **FULL APPROVAL.**

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment /modification prior to its implementation. In case you have further queries, please quote the above reference number.

PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of 3 years from the date of issue. Thereafter Recertification must be applied for on an annual basis.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

[redacted]

Dr Shenuka Singh (Chair)
Humanities & Social Scinces Research Ethics Committee

/pm

cc Supervisor: Professor Manoj Maharaj
cc Academic Leader Research: Dr Muhammad Hoque
cc School Administrator: Ms Zarina Bullyraj

Humanities & Social Sciences Research Ethics Committee
Dr Shenuka Singh (Chair)
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000

Appendix B: Proposal Approval

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI
Graduate School of Business and Leadership

Student Name:	Mpho Mzingelwa
Student No.:	215082567
Name of School:	Graduate school of Business & Leadership
Proposed Qualification:	Doctoral Of Business Administration / Doctor Of Philosophy

Title: Livestock Identification and Tracking System: Case Study of South Africa

Panel Decision: The panel has approved the proposal. Now you can apply for ethical clearance. Good luck with your study.

Best regards

[redacted]

Dr Muhammad Hoque
Academic Leader: Higher Degrees and Research
Graduate School of Business & Leadership
University of KwaZulu-Natal (Westville Campus)
South Africa
E-Mail: hoque@ukzn.ac.za

Appendix D: Informed Consent

UKZN HUMANITIES AND SOCIAL SCIENCES RESEARCH ETHICS COMMITTEE (HSSREC)

Information Sheet and Consent to Participate in Research

Date: 17 January 2017

Dear Sir/Madam,

My name is Mpho Mzingelwa (phone number: 031 260 8521; email address: mzingelwa@ukzn.ac.za). I am a doctoral student from the Graduate School of Business and Leadership, College of Law and Management, University of Kwazulu-Natal. My supervisor is Professor Manoj Maharaj (phone number: 031 260 8023; email address: maharajms@ukzn.ac.za).

You are being invited to consider participating in a study that involves research on "Livestock Identification and Tracking System: Case Study of South Africa"

The aim and purpose of this research is to explore how Information Communication Technology (ICT) can 'help' address the problem of livestock-theft in South Africa.

The study is expected to enroll 63 participants in total, from various institutions and social structures in all the nine provinces of South Africa. The duration of your participation if you choose to enroll and remain in the study is expected to be +-30 minutes.

Your participation in the research is voluntary (you may withdraw participation at any point), and that in the event of refusal/withdrawal of participation you will not incur penalty. No personal information will be collected, i.e. all the answers provided in the interview schedule / questionnaire will remain anonymous and confidential.

This study has been ethically reviewed and approved by the UKZN Humanities and Social Sciences Research Ethics Committee (approval number **HSS/0109/017D).**

In the event of any problems or concerns/questions you may contact the researcher at (phone: 0603371570; email: mzingelwa@ukazn.ac.za) or the UKZN Humanities & Social Sciences Research Ethics Committee, contact details as follows:

HUMANITIES & SOCIAL SCIENCES RESEARCH ETHICS ADMINISTRATION

Research Office, Westville Campus

Govan Mbeki Building

Private Bag X 54001
Durban
4000

KwaZulu-Natal, SOUTH AFRICA

Tel: 27 31 2604557- Fax: 27 31 2604609

Email: HSSREC@ukzn.ac.za

CONSENT to participate in the research study

I (Name: ___________________________) have been informed about the study entitled “Livestock Identification and Tracking System: Case Study of South Africa” by Mpho Mzingelwa.

I understand the purpose and procedures of the study.

I have been given an opportunity to answer questions about the study and have had answers to my satisfaction.

I declare that my participation in this study is entirely voluntary and that I may withdraw at any time.

If I have any further questions/concerns or queries related to the study I understand that I may contact the researcher at (0603371570 / mzingelwa@ukzn.ac.za).

If I have any questions or concerns about my rights as a study participant, or if I am concerned about an aspect of the study or the researchers then I may contact:

HUMANITIES & SOCIAL SCIENCES RESEARCH ETHICS ADMINISTRATION

Research Office, Westville Campus

Govan Mbeki Building

Private Bag X 54001
Durban
4000

KwaZulu-Natal, SOUTH AFRICA

Tel: 27 31 2604557 - Fax: 27 31 2604609

Email: HSSREC@ukzn.ac.za

_____________________ _____________________

Signature of Participant Date

_____________________ _____________________

Signature of Witness Date

(Where applicable)

_____________________ _____________________

Signature of Translator Date

(Where applicable)

Appendix E: Gatekeepers` Letter

South African Police Service — *Suid-Afrikaanse Polisiediens*

Privaatsak Private Bag X94	Pretoria 0001	Faks No. Fax No.	(012) 393 2616

Your reference/U verwysing:
My reference/My verwysing: 3/34/2
Enquiries/Navrae: **Lt Col Joubert**
Intern Mahamba
Tel: **(012) 393 3118**
(012) 393 2423/4370
Email: **JoubertG@saps.gov.za**
MahambaS@saps.gov.za

THE NATIONAL COMMISSIONER
SOUTH AFRICAN POLICE SERVICE
PRETORIA
0001

M Mzingelwa
UNIVERSITY OF KWAZULU-NATAL

RE: PERMISSION TO CONDUCT RESEARCH IN SAPS: LIFESTOCK IDENTIFICATION AND TRACKING SYSTEM: CASE STUDY OF SOUTH AFRICA: DOCTORAL: UNIVERSITY OF KWAZULU-NATAL: RESEARCHER: M MZINGELWA

The above subject matter refers.

You are hereby granted approval for your research study on the above mentioned topic in terms of National Instruction 1 of 2006.

Further arrangements regarding the research study may be made with the following offices:

Provincial Commissioner: Eastern Cape:

- **Contact Person:** Lt Col Dyosini
- **Contact Details:** (040) 608 8525

Provincial Commissioner: KwaZulu-Natal:

- **Contact Person:** Col van der Linde
- **Contact Details:** (031) 325 4841

RE: PERMISSION TO CONDUCT RESEARCH IN SAPS: LIFESTOCK IDENTIFICATION AND TRACKING SYSTEM: CASE STUDY OF SOUTH AFRICA: DOCTORAL: UNIVERSITY OF KWAZULU-NATAL: RESEARCHER: M MZINGELWA

Provincial Commissioner: Free State:

- **Contact Person:** Lt Col Nair
- **Contact Details:** (051) 507 7030/7028

Divisional Commissioner: Detective Service:

- **Contact Person:** Brig Kgopodithata
- **Contact Details:** (012) 393 3780

Kindly adhere to par 6 of our letter signed on the **2016/09/28** with the same above reference number.

[redacted] **LIEUTENANT GENERAL**
DIVISIONAL COMMISSIONER: RESEARCH
DR BM ZULU

DATE: 2017/03/01

SUID-AFRIKAANSE POLISIEDIENS **SOUTH AFRICAN POLICE SERVICE**

Privaatsak/Private Bag X 94

Verwysing/Reference:	3/34/2
Navrae/Enquiries:	Lt Col Joubert Intern Mahamba
Telefoon/Telephone:	(012) 393 3118 (012) 393 2423/4370

DIVISION: RESEARCH
SOUTH AFRICAN POLICE SERVICE
PRETORIA
0001

A. The Provincial Commissioner
EASTERN CAPE

B. The Provincial Commissioner
KWAZULU-NATAL

C. The Provincial Commissioner
FREE STATE

D. The Divisional Commissioner
DETECTIVE SERVICE

PERMISSION TO CONDUCT RESEARCH IN SAPS: LIFESTOCK IDENTIFICATION AND TRACKING SYSTEM: CASE STUDY OF SOUTH AFRICA; DOCTORAL; UNIVERSITY OF KWAZULU-NATAL; RESEARCHER: M MZINGELWA

A-D 1. The above subject matter refers.

2. The researcher, Mr M Mzingelwa is conducting a research study with the aim to analyse the current South African situation with regard to identification and tracking of livestock.

3. The researcher is requesting permission to interview SAPS Stock Theft Unit members in certain areas in the following provinces:

3.1 Eastern Cape (Areas: Maluti, Sulenkama, Qumbu, Mthatha, Mount Frere);

3.2 Kwazulu-Natal (Areas: Amangwe, Bulwer, Utrecht, Ladysmith)

PERMISSION TO CONDUCT RESEARCH IN SAPS: LIFESTOCK IDENTIFICATION AND TRACKING SYSTEM: CASE STUDY OF SOUTH AFRICA; DOCTORAL; UNIVERSITY OF KWAZULU-NATAL; RESEARCHER: M MZINGELWA

3.3 Free State (Area: Bethlehem)

4. The proposal was perused according to National Instruction 1 of 2006. This office recommends that permission be granted for the research study, subject to the final approval and further arrangements by the offices of the Provincial Commissioners: Eastern Cape, Kwazulu-Natal, Free State and the Divisional Commissioner: Detective Service.

5. We hereby request the final approval by your office if you concur with our recommendation. Your office is also at liberty to set terms and conditions to the researcher to ensure that compliance standards are adhered to during the research process and that research has impact to the organisation.

6. If approval granted by your office, this office will obtain a signed undertaking from researcher prior to the commencement of the research which will include your terms and conditions if there are any and the following:

6.1. The research will be conducted at his/her exclusive cost.

6.2 The researcher will conduct the research without the disruption of the duties of members of the Service and where it is necessary for the research goals, research procedures or research instruments to disrupt the duties of a member, prior arrangements must be made with the commander of such member.

6.3 The researcher should bear in mind that participation in the interviews must be on a voluntary basis.

6.4 The information will at all times be treated as strictly confidential.

PERMISSION TO CONDUCT RESEARCH IN SAPS: LIFESTOCK IDENTIFICATION AND TRACKING SYSTEM: CASE STUDY OF SOUTH AFRICA; DOCTORAL; UNIVERSITY OF KWAZULU-NATAL; RESEARCHER: M MZINGELWA

6.5 The researcher will provide an annotated copy of the research work to the Service.

7. If approval granted by your office, for smooth coordination of research process between your office and the researcher, the following information is kindly requested to be forwarded to our office:

- **Contact person**: Rank, Initials and Surname.
- **Contact details**: Office telephone number and email address.

8. A copy of the approval (if granted) and signed undertaking as per paragraph 6 supra to be provided to this office within 21 days after receipt of this letter.

9. Your cooperation will be highly appreciated.

[redacted] **LIEUTENANT GENERAL**
DIVISIONAL COMMISSIONER: RESEARCH
DR BM ZULU

DATE: 2016/09/28

Appendix F: Interview Schedule – SAPS`s Stock Theft Units

Preamble

PROBLEM: South Africa is faced with a problem of livestock theft, as well as cross-border livestock theft into neighboring countries such as Swaziland, Lesotho, Swaziland, etc.

- South Africa loses more than R700 million annually through theft of livestock.
- Livestock theft is a national societal phenomenon that needs a multi-stakeholder approach (government, livestock farmers, communities, traditional authority, and industries).

AIM: The research study aims at exploring how livestock stakeholders (livestock farmers, government, communities, and traditional authority) can utilise Information and Commination Technology (ICT) to deal with livestock theft in South Africa.

GOAL: The goal of research study is to propose a MODEL of a livestock identification and tracking system.

- The proposed MODEL would be a representation of a national comprehensive/holistic livestock identification and tracking system.

Appendix 1: Interview Schedule - South Africa Police Services (SAPS)

Semi-structured interview for the informants from the SAPS

Section 1: Introduction

1.1. What is your core area of specialisation?

1.2. What is your experience in your area of specialisation?

1.3. What is your role in your organisation (SA Police Service)?

1.4. How many years of experience do have in your role at your organisation (SA Police Service)?

Section 2: General Issues Pertaining to Livestock Theft

2.1. What is your view about theft of livestock in your district/region/province/South Africa?

2.2. What is your view about the impact of livestock in your district/region/province/South Africa?

2.3. What is your view about the use of ICT to supplement the traditional methods when dealing with livestock theft?

Section 3: Reporting of Stolen Livestock

3.1. How do people report the cases of livestock theft to the SA Police Services?

3.2. Can you briefly explain the process and procedures one undertakes when he/she is reporting a case of livestock theft?

3.3. When one reports a case of stolen livestock to the SA Police Services, what is the crucial information (data) about the livestock owner being captured onto the docket and onto Crime Administration System (CSM)?

3.4. When one reports a case of stolen livestock to the SA Police Services, what is the crucial information (data) about the stolen livestock (livestock itself) being captured onto the docket and onto CSM?

3.5. Besides the livestock owner information (data) and stolen livestock (livestock itself) information (data), what other information (data) is being captured onto the docket and onto CSM during the reporting of stolen livestock?

3.6. What happens when livestock identification marks or livestock branding had NOT priorly been captured onto Animal Identification System (AIS)?

3.7. How do Police officials access AIS?

Access to AIS	
via web browser (mobile phone)	
via web browser (computer)	
via sms (mobile phone)	
via mms (mobile phone)	
via desktop application (computer)	
via mobile application (mobile phone)	
Other (please specify):	

3.8. Is Crime Administration System (CAS) integrated/linked to Animal Identification System?

Section 4: Searching for the Stolen Livestock (identification and tracking of livestock)

4.1. How do SA Police Services Officers go about searching for the reported stolen livestock?

4.2. Who (government department, institution, social structure, etc) is involved in collaboration with the SA Police Services Officers when searching for the reported stolen livestock?

4.4. How can communities collaborate/work with the Police in searching for the stolen livestock?

4.5. How can traditional authority (e.g. chiefs, headmen) collaborate/work with the Police in searching for the stolen livestock?

4.6 How can stock theft forums collaborate/work with the Police in searching for the stolen livestock?

4.7. How can abattoirs collaborate/work with the Police in dealing with the livestock theft?

4.8. How can collaborate/work with the Police in dealing with the livestock theft?

4.9. How can industries organizations collaborate/work with the Police in dealing with the livestock theft?

4.10. What is the crucial information from the docket that the Police carry around when searching the stolen livestock?

4.11. What kind/form of electronic devices (ICTs) do SA Police Service Officers utilise while searching for the lost livestock?

Section 5: Recovery of Stolen livestock (livestock identification)

5.1. Upon the recovery of livestock, how do livestock holders prove the ownership of livestock?

5.2. How do Police handle disputes over ownership of livestock between/among people claiming ownership of the recovered livestock?

Section 6: Prevention of Livestock Theft through a multi-stakeholder approach (Government, Livestock Farmers, Industries, and Traditional Authority in dealing with Theft of Livestock and Stray Livestock).

6.1. How can livestock farmers work together with police, communities, local government, and traditional authority to prevent or minimize the theft of livestock in South Africa?

6.3. How can government work together with livestock farmers, communities, industries and traditional authority to prevent or minimize the cross-border theft of livestock from South Africa into neighbouring countries such as Namibia, Botswana, Lesotho, Zimbabwe, Mozambique, and Swaziland?

6.4. How can ICT be effectively and efficiently used by the livestock stakeholders (livestock farmers, communities, government, industries, and traditional authority) to deal with theft of livestock in South Africa?

Section 7: Other Comments / Suggestions / Views / Opinions

7.1. Do you have any other comments / views on livestock theft in South Africa?

THANK YOU FOR YOUR TIME

Appendix G: Interview Schedule – Stock Theft Preventative Forum

Preamble

PROBLEM: South Africa is faced with a problem of livestock theft, as well as cross-border livestock theft into neighboring countries such as Swaziland, Lesotho, Swaziland, etc.

- South Africa loses more than R700 million annually through theft of livestock.
- Livestock theft is a national societal phenomenon that needs a multi-stakeholder approach (government, livestock farmers, communities, traditional authority, and industries).

AIM: The research study aims at exploring how livestock stakeholders (livestock farmers, government, communities, and traditional authority) can utilise Information and Commination Technology (ICT) to deal with livestock theft in South Africa.

GOAL: The goal of research study is to propose a MODEL of a livestock identification and tracking system.

- The proposed MODEL would be a representation of a national comprehensive/holistic livestock identification and tracking system.

Semi-structured interview for the informants from the Stock Theft Preventative Forum

Section 1: Introduction

1.5. What is your core area of specialisation?

1.6. What is your experience in your area of specialisation?

1.7. What is your role in the Livestock Theft Preventative Forum?

1.8. How many years have you been involved in the Livestock Theft Preventative Forum?

Section 2: General Issues Pertaining to Livestock Theft

2.1. What is your view about theft of livestock in South Africa?

2.2. What is your view about the impact of livestock in South Africa?

Section 3: Management of Livestock against Theft

3.1. Based on your experience with South African subsistence and smallholder livestock farmers, how do South African subsistence and smallholder livestock farmers protect their livestock against theft?

3.4. What role(s) can the people of the farming communities play against livestock theft?

3.5. What role(s) can the traditional authority (e.g. headmen, chiefs) play against theft of livestock in their respective communities?

3.6. How can government work together with livestock farmers, communities, industries, and traditional authorities to prevent or minimize theft of livestock in South Africa?

3.7. How can government work together with livestock farmers, communities, industries, and traditional authorities to prevent or minimize the problem of stray livestock in South Africa?

3.8. How can butcheries, slaughter houses, and buyers of livestock in general prove that they are NOT buying stolen livestock in South Africa?

3.9. With regards to cross-border theft of livestock, how can government work together with livestock farmers, communities, industries, and traditional authorities to prevent or minimize theft of livestock from South Africa into neighboring countries such as Lesotho, Swaziland, Namibia, Zimbabwe, Mozambique and Botswana?

Section 4: The Role of ICT in Managing Livestock

4.1. Based on your experience with subsistence and smallholder livestock farmers in South Africa, how do South African subsistence and smallholder livestock farmers use ICT to manage their livestock?

4.2.. What is your view about the use of ICT to supplement the traditional methods when dealing with livestock theft in South Africa?

4.2. How can ICT help prevent or minimize theft of livestock in South Africa?

Section 5: Social/Cultural and Ethical Issues on Animals (livestock)

5.1. Based on your experience with South African livestock farmers, what are the social/cultural issues against the use of technology on animals (livestock)?

5.2. Based on your experience with South African livestock farmers, what are the ethical issues against the use of technology on animals (livestock)?

Section 6: Other Comments / Suggestions / Views / Opinions

6. 1. Do you have any other comments / views on livestock theft in South Africa?

THANK YOU FOR YOUR TIME

Appendix I: Interview Schedule – Livestock Farmers

Preamble

PROBLEM: South Africa is faced with a problem of livestock theft, as well as cross-border livestock theft into neighboring countries such as Swaziland, Lesotho, Swaziland, etc.

- South Africa loses more than R700 million annually through theft of livestock.
- Livestock theft is a national societal phenomenon that needs a multi-stakeholder approach (government, livestock farmers, communities, traditional authority, and industries).

AIM: The research study aims at exploring how livestock stakeholders (livestock farmers, government, communities, and traditional authority) can utilise Information and Commination Technology (ICT) to deal with livestock theft in South Africa.

GOAL: The goal of research study is to propose a MODEL of a livestock identification and tracking system.

- The proposed MODEL would be a representation of a national comprehensive/holistic livestock identification and tracking system.

Semi-structured interview with Livestock Farmers

Section 1: Introduction

1.1. Can you please describe your livestock holding?

1.2. Where is your farm located/based, and how big is the farm?

1.3. Can you please describe where does your livestock sleep at night?

1.4. How many years have you been a livestock farmer?

1.5. Can you please describe the livestock grazing area?

Section 2: General Issues Pertaining to Livestock Theft

2.1. What effects does livestock theft have on you, your farm and family?

2.2. What effects does livestock theft have on your community?

2.3. How much assistance do you receive from the Police?

2.4. How much assistance does your community receive from the Police?

2.5. How much assistance do you receive from the Stock Theft Forms?

2.4. How much assistance do you receive from your Community?

Section 3: Management of Livestock against Theft

3.1. How do you protect your farm and livestock against theft?

3.2. How does your community help livestock farmers against theft?

3.2. How do you identify your livestock?

3.4. How do you use your mobile phone for your livestock farming?

Section 4: Reporting of Stolen Livestock

4.1. How do livestock farmers in your community go about reporting a case of livestock theft to the Traditional Authority (e.g. headmen, chief)?

4.2. How do livestock farmers in your community go about reporting a case of livestock theft to the Police?

4.3. Besides, the Traditional Authority and Police, whom else do livestock theft cases get to be reported to?

Section 5: Searching for the Stolen Livestock (identification and tracking of livestock)

5.1. How do people in your community go about searching for the stolen livestock?

5.2. How do the Police in your community help when searching for the stolen livestock?

5.3. How do Stock Theft Forums in your community help when searching for the stolen livestock?

5.8. How do Community Radio Stations in your community help when searching for the stolen livestock?

Section 6: Prevention of Livestock Theft through a Multi-stakeholder Approach

6.1. What role can the Traditional Authority play in preventing theft of livestock?

6.2. What role can the Communities play in preventing theft of livestock?

6.3. What role can Businesses play in preventing theft of livestock?

6.4. What role can the Police and Government can play in preventing theft of livestock?

Section 7: Other Comments / Suggestions / Views / Opinions

THANK YOU FOR YOUR TIME

Appendix J: Interview Schedule – Traditional Authority

Preamble

PROBLEM: South Africa is faced with a problem of livestock theft, as well as cross-border livestock theft into neighboring countries such as Swaziland, Lesotho, Swaziland, etc.

- South Africa loses more than R700 million annually through theft of livestock.
- Livestock theft is a national societal phenomenon that needs a multi-stakeholder approach (government, livestock farmers, communities, traditional authority, and industries).

AIM: The research study aims at exploring how livestock stakeholders (livestock farmers, government, communities, and traditional authority) can utilise Information and Commination Technology (ICT) to deal with livestock theft in South Africa.

GOAL: The goal of research study is to propose a MODEL of a livestock identification and tracking system.

- The proposed MODEL would be a representation of a national comprehensive/holistic livestock identification and tracking system.

Semi-structured interview for the Traditional Authority

Section 1: Introduction

1.9. What are your core day-to-day duties as the traditional authority leader in your community?

1.10. How many people in the Traditional Authority do you work with, and what are their roles?

1.11. How many years of experience have been a traditional authority leader in your community?

Section 2: General Issues Pertaining to Livestock Theft

2.1. What effects does livestock theft have on your community?

2.2. How much assistance/support do you receive from your community in dealing with theft of livestock?

2.3. How much assistance do you receive from the Police?

2.4. How much assistance do you receive from the Stock Theft Forms?

2.5. What customary laws does your community have towards theft of livestock?

2.6. What has the Traditional Authority been doing to prevent or deal with the theft of livestock?

Section 3: Reporting of Stolen Livestock (livestock identification)

3.1. As the Traditional Authority leader of the community, how do you handle and deal with livestock theft cases that are reported to you?

3.2. As the Traditional Authority leader of the community, what do you use to capture, record and keep the cases of reported livestock theft?

3.3. How do you use a mobile phone to communicate with people in your community when dealing with livestock theft cases?

Section 4: Searching for the Stolen Livestock (identification and tracking of livestock)

4.1. How does your Traditional Authority go about searching for the reported stolen livestock?

Section 5: Recovery of Stolen livestock (livestock identification)

5.3. How does your Traditional Authority handle disputes over ownership of livestock between/among people claiming ownership of the recovered livestock?

5.4. If disputes over ownership of livestock between/among people claiming ownership of recovered livestock are to be escalated, to whom should they be escalated?

Section 6: Prevention of Livestock Theft through a multi-stakeholder approach (Government, Livestock Farmers, Industries, and Traditional Authority in dealing with Theft of Livestock and Stray Livestock).

6.1. What is the Traditional Authority doing to prevent theft of livestock?

6.2. Are you involved in a partnership/forum/union/movement that seeks to address livestock theft?

6.2. How can livestock farmers work together with Police, communities, local government, and traditional authority to prevent or minimize the theft of livestock in your community?

Section 7: Other Comments / Suggestions / Views / Opinions

7.1. Do you have any other comments / views on livestock theft?

Appendix K: Questionnaire – Animal (Livestock) Specialists

Preamble

PROBLEM: South Africa is faced with a problem of livestock theft, as well as cross-border livestock theft into neighboring countries such as Swaziland, Lesotho, Swaziland, etc.

- South Africa loses more than R700 million annually through theft of livestock.
- Livestock theft is a national societal phenomenon that needs a multi-stakeholder approach (government, livestock farmers, communities, traditional authority, and industries).

AIM: The research study aims at exploring how livestock stakeholders (livestock farmers, government, communities, and traditional authority) can utilise Information and Commination Technology (ICT) to deal with livestock theft in South Africa.

GOAL: The goal of research study is to propose a MODEL of a livestock identification and tracking system.

- The proposed MODEL would be a representation of a national comprehensive/holistic livestock identification and tracking system.

Questionnaire

Section 1 – Introduction

1.12. What is your core area of specialisation?

____

1.13. What is your experience in your core area of specialisation?

0-3 years	
4-6 years	
7-10 years	
More than 10 years	

1.14. What is your role in your organisation?

____

1.15. How many years have you been working in your organisation?

0-3 years	
4-6 years	
7-10 years	
More than 10 years	

Section 2 – General Issues Pertaining to Livestock Theft

2.1. What is your view about theft of livestock in your area/district/region/province/South Africa?

2.2. What is your view about the impact of livestock in your area/district/region/province/South Africa?

2.3. What is your view about the use of Information and Communication Technology (ICT) to supplement the traditional methods when dealing with livestock theft in South Africa?

Section 3 – Management of Livestock against Theft

3.1. Based on your experience with South African subsistence and smallholder livestock farmers, how do South African subsistence and smallholder livestock farmers protect their livestock against theft?

____

3.2. What role(s) can the people of the farming communities play against livestock theft?

____

3.3. What role(s) can the traditional authority (e.g. headmen, chiefs) play against theft of livestock in their respective communities?

____

3.4. How can government work together with livestock farmers, communities, industries, and traditional authorities to prevent or minimize theft of livestock in South Africa?

____

3.5. How can butcheries (slaughter houses), and buyers of livestock in general prove that they are NOT buying stolen livestock in South Africa?

____

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___

___

3.6. How can government work together with livestock farmers, communities, industries, and traditional authorities to prevent or minimize the buying of stolen livestock by the butcheries, slaughter houses, and 'black markets' in South Africa?

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3.7. With regards to cross-border theft of livestock, how can government work together with livestock farmers, communities, industries, and traditional authorities to prevent or minimize theft of livestock from South Africa into neighboring countries such as Lesotho, Swaziland, Namibia, Zimbabwe, Mozambique and Botswana?

___

___

___

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___

Section 4 – The Role of ICT in Managing Livestock

4.1. Based on your experience with subsistence and smallholder livestock farmers in South Africa, how do South African subsistence and smallholder livestock farmers use ICT to manage their livestock?

___

___

___

___

___

4.2. How can ICT help prevent or minimize theft of livestock in South Africa?

___

___

___

___

___

___

Section 5 – Social/Cultural and Ethical Issues on Animals (livestock)

5.1. Based on your experience with South African livestock farmers, what are the social/cultural issues against the use of technology on animals (livestock)?

____
____
____
_____

5.2. Based on your experience with South African livestock farmers, what are the ethical issues against the use of technology on animals (livestock)?

____
____
____
____
____

Section 6 – Prevention of Livestock Theft through a Multi-stakeholder Approach (Government, Livestock Farmers, Industries, and Traditional Authority in dealing with Theft of Livestock).

6.1. What role can the Traditional Authority play in preventing theft of livestock?

____
____
____
_____

6.2. What role can the Communities play in preventing theft of livestock?

____
____
____
_____

6.3. What role can Businesses play in preventing theft of livestock?

____
____
____
_____

6.4. What role can the Police and Government can play in preventing theft of livestock?

6.5. How can government work together with livestock farmers, communities, industries and traditional authority to prevent or minimize the cross-border theft of livestock from South Africa into neighbouring countries such as Namibia, Botswana, Lesotho, Zimbabwe, Mozambique, and Swaziland?

6.6. How can technology (ICT) be effectively and efficiently used by the livestock stakeholders (livestock farmers, communities, government, industries, and traditional authority) to deal with theft of livestock?

Section 7 – Other Comments / Suggestions / Views / Opinions

7.1. You may write other comments/suggestions/views/opinions below

THANK YOU FOR YOUR TIME!

Appendix L: Questionnaire – ICT & Information Systems Specialists

Preamble

PROBLEM: South Africa is faced with a problem of livestock theft, as well as cross-border livestock theft into neighboring countries such as Swaziland, Lesotho, Swaziland, etc.

- South Africa loses more than R700 million annually through theft of livestock.
- Livestock theft is a national societal phenomenon that needs a multi-stakeholder approach (government, livestock farmers, communities, traditional authority, and industries).

AIM: The research study aims at exploring how livestock stakeholders (livestock farmers, government, communities, and traditional authority) can utilise Information and Commination Technology (ICT) to deal with livestock theft in South Africa.

GOAL: The goal of research study is to propose a MODEL of a livestock identification and tracking system.

- The proposed MODEL would be a representation of a national comprehensive/holistic livestock identification and tracking system.

Questionnaire

Section 1: Introduction

1.16. What is your core area of specialisation within Information and Communication Technology (ICT)?

____

____

1.17. What is your experience in ICT?

0-3 years	
4-6 years	
7-10 years	
More than 10 years	

1.18. What is your role in your organisation?

____

____

Section 2: The Role of ICT in Managing Livestock against Theft

2.1. How can ICT help prevent or minimize the problem of livestock theft in South Africa?

____

____

____

____

2.2. How can South African substance and small-holder livestock farmers utilise ICT to protect their livestock against theft?

____

____

____

2.3. How can government through utilization of ICT work together with livestock farmers, communities, industries and traditional authority to prevent or minimize the theft of livestock in South Africa?

____

____

____

____

____

Section 3: Technological Components of a Holistic / Comprehensive Information System for Electronically Identifying and Tracking Livestock within the South African Context

3.1. Please rank the following Hardware Technological Tools according their importance for the design and development of an information system that can identify and track livestock within the South African context.

(1 = Very Important; 2 = Important; 3 = May be Important; 4 = Not important; 5 = Not relevant).

Hardware Technological Tools	**1**	**2**	**3**	**4**	**5**
Radio					
Computers					
Telephones					
Mobile Phones					
Television (TV)					
Surveillance (e.g. CCTV Cameras)					
Other (please Specify):					

3.2. Please rank the following Application Software and Communication Technologies according their importance for the design and development of an information system that can identify and track livestock within the South African context.

(1 = Very Important; 2= Important; 3 = May be Important; 4 = Not important; 5 = Not relevant).

Application Software and Communication Technologies	**1**	**2**	**3**	**4**	**5**
Toll-free Phone Number					
SMS					
MMS					
Online Social Media					
Automated Telephone Voice					
Mobile App					
Web Application					
Desktop Client Application					
E-mail					

3.4. Please rank the following Wireless Technology Coverage according their importance for the design and development of an information system that can identify and track livestock within the South African context.

(1 = Very Important; 2 = Important; 3 = May be Important; 4 = Not important; 5 = Not relevant).

Wireless Technology Coverage	**1**	**2**	**3**	**4**	**5**
2G					
3G					
4G					
Wi-Fi Hot Spots					
LTE					
WiMAX					
Other (please specify):					

3.5. Please rank the following Identifier and Tracker Technologies according their importance for the design and development of an information system that can identify and track livestock within the South African context.

(1 = Very Important; 2 = Important; 3 = May be Important; 4 = Not important; 5 = Not relevant).

Identification and Tracking Technology	**1**	**2**	**3**	**4**	**5**
Radio-Frequency Identification (RFID)					
Global Positioning System (GPS)					
Location Based Services (LBS)					
Real-time Locating Systems (RTLS)					
Surveillance Technology (e.g. CCTV cameras)					
Image Processing (Biometric Scanning)					
Other (please specify):					

Section 4: The Role of Emerging Technologies in Livestock Management

4.1. How can emerging technologies such as Internet of Things (IoT), Big Data & Analytics, Social Media, VoIP, Mobile Apps, and Cloud Computing play a role in managing livestock?

Please write your insights/views in the table below:

Emerging Technologies	**Role in Managing Livestock?**
Internet of Things (IoT)	
Big Data & Analytics	

Social Media	
VoIP	
Mobile Apps	
Cloud Computing	
Other (please specify):	

Section 5: Prevention of Livestock Theft through a Multi-stakeholder Approach (Government, Livestock Farmers, Industries, and Traditional Authority in dealing with Theft of Livestock and Stray Livestock).

5.1. What role can the Traditional Authority play in preventing theft of livestock?

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5.2. What role can the Communities play in preventing theft of livestock?

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5.3. What role can Businesses play in preventing theft of livestock?

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5.4. What role can the Police and Government can play in preventing theft of livestock?

5.5. How can government work together with livestock farmers, communities, industries and traditional authority to prevent or minimize the cross-border theft of livestock from South Africa into neighbouring countries such as Namibia, Botswana, Lesotho, Zimbabwe, Mozambique, and Swaziland?

5.6. How can technology (ICT) be effectively and efficiently used by the livestock stakeholders (livestock farmers, communities, government, industries, and traditional authority) to deal with theft of livestock?

Section 6: Other Comments / Suggestions / Views / Opinions

6.1. You may write your comments/suggestions/views/opinions below.

THANK YOU FOR YOUR TIME!

Appendix M: Critical Appraisal Skill Programme (CASP)

CASP Checklist: 10 questions to help you make sense of a **Systematic Review**

How to use this appraisal tool: Three broad issues need to be considered when appraising a systematic review study:

- Are the results of the study valid? (Section A)
- What are the results? (Section B)
- Will the results help locally? (Section C)

The 10 questions on the following pages are designed to help you think about these issues systematically. The first two questions are screening questions and can be answered quickly. If the answer to both is "yes", it is worth proceeding with the remaining questions. There is some degree of overlap between the questions, you are asked to record a "yes", "no" or "can't tell" to most of the questions. A number of italicised prompts are given after each question. These are designed to remind you why the question is important. Record your reasons for your answers in the spaces provided.

About: These checklists were designed to be used as educational pedagogic tools, as part of a workshop setting, therefore we do not suggest a scoring system. The core CASP checklists (randomised controlled trial & systematic review) were based on JAMA 'Users' guides to the medical literature 1994 (adapted from Guyatt GH, Sackett DL, and Cook DJ), and piloted with health care practitioners.
For each new checklist, a group of experts were assembled to develop and pilot the checklist and the workshop format with which it would be used. Over the years overall adjustments have been made to the format, but a recent survey of checklist users reiterated that the basic format continues to be useful and appropriate.
Referencing: we recommend using the Harvard style citation, i.e.: *Critical Appraisal Skills Programme (2018). CASP (insert name of checklist i.e. Systematic Review) Checklist. [online] Available at: URL. Accessed: Date Accessed.*

Paper for appraisal and reference:……………………………………………………………………………………………….

Section A: Are the results of the review valid?

1. Did the review address a clearly focused question?

Yes	
Can't Tell	
No	

HINT: An issue can be 'focused' In terms of
- the population studied
- the intervention given
- the outcome considered

Comments:

2. Did the authors look for the right type of papers?

Yes	
Can't Tell	
No	

HINT: 'The best sort of studies' would
- address the review's question
- have an appropriate study design (usually RCTs for papers evaluating interventions)

Comments:

Is it worth continuing?

3. Do you think all the important, relevant studies were included?

Yes ☐ Can't Tell ☐ No ☐

HINT: Look for
- which bibliographic databases were used
- follow up from reference lists
- personal contact with experts
- unpublished as well as published studies
- non-English language studies

Comments:

4. Did the review's authors do enough to assess quality of the included studies?

Yes ☐ Can't Tell ☐ No ☐

HINT: The authors need to consider the rigour of the studies they have identified. Lack of rigour may affect the studies' results ("All that glisters is not gold" Merchant of Venice – Act II Scene 7)

Comments:

5. If the results of the review have been combined, was it reasonable to do so?

Yes ☐ Can't Tell ☐ No ☐

HINT: Consider whether
- results were similar from study to study
- results of all the included studies are clearly displayed
- results of different studies are similar
- reasons for any variations in results are discussed

Comments:

Section B: What are the results?

6. What are the overall results of the review?

HINT: Consider
- If you are clear about the review's 'bottom line' results
- what these are (numerically if appropriate)
- how were the results expressed (NNT, odds ratio etc.)

Comments:

7. How precise are the results?

HINT: Look at the confidence intervals, if given

Comments:

Section C: Will the results help locally?

8. Can the results be applied to the local population?

Yes ☐ Can't Tell ☐ No ☐

HINT: Consider whether
- the patients covered by the review could be sufficiently different to your population to cause concern
- your local setting is likely to differ much from that of the review

Comments:

9. Were all important outcomes considered?

Yes ☐ Can't Tell ☐ No ☐

HINT: Consider whether
- there is other information you would like to have seen

Comments:

10. Are the benefits worth the harms and costs?

Yes ☐ Can't Tell ☐ No ☐

HINT: Consider
- even if this is not addressed by the review, what do **you** think?

Comments:

Appendix N: Proof of Language Editing – Letter

The Language Editing Spirit
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+27 (0) 76 811 9595
Dr.fa.ruffin@gmail.com

18 July 2023

This letter is to certify that I provided language editing services for the thesis of Mr Mpho Mzingelwa, Student number 215082567, a doctoral candidate at the University of KwaZulu-Natal in South Africa. The thesis is entitled:

Livestock Identification and Tracking System for Controlling Livestock Theft: Case Study of South Africa

Language editing was performed on the preliminary pages and the text of the thesis. This means that I ensured structural use of words, clauses, and phrases; subject–verb agreement; proper use of singular and plural nouns; parallelisms, tense, conjugations, spelling and punctuation, and syntax according to language editing conventions. I edited the document using track changes subject to approval of the candidate and supervisor. I also provided a four-page Editor's Report with further editing suggestions and recommendations.

Should you require additional information, feel free to contact the undersigned.

____

Professor Fayth A Ruffin